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NOTICE TO CONTRIBUTORS

General

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Typescript

The original and one carbon copy are required, on one side only of foolscap paper, double spaced, with a left-hand margin of at least one inch and a quarter. Reasonably heavy good-quality paper should be used, flimsy paper delays the machine operator and consequently increases the cost of printing.

A brief summary is required, at the beginning of the paper. It should indicate the scope of the paper and give the principal results, and should be suitable for reproduction by abstracting journals as it stands.

All matter to be printed in italic type (e.g., generic and specific names) must be underlined.

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Tabular matter costs more to print than letterpress and should therefore be kept to a minimum, bearing in mind, however, that a well-planned table can take the place of a much greater area of letterpress.

Wherever possible, tables should be arranged to fit upright on the page, not sideways. They will be printed in 8-point type.

All tables, however brief, should be numbered in arabic numerals. Numerous very small tables should be avoided.

Titles should be as brief as possible.

Units of measurement should be placed in parentheses at the head of the column, not in the body of the table. Descriptive notes should be kept to a minimum, and abbreviations used wherever possible. For abbreviations, etc., the usage followed is that of British Standard 1991, Letter Symbols, Signs, and Abbreviations. Part 1. General.

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These are to be numbered consecutively in arabic numerals, regardless of whether they are half-tones (photographs) or line blocks (graphs, etc.). Each must be referred to in the text, and only such figures as are essential to elucidate the text can be published.

The author's name, the title of the paper (abbreviated), and the figure number should be written lightly in soft pencil on the back of each figure.

Photographic prints should be on glossy paper, and may be the same size as or larger than the printed picture. Components of a composite figure should be firmly mounted on white card, and lettered as required A, B, C, etc.

Graphs should preferably be drawn about twice the final size, with the curves evenly inked throughout. Great care should be taken to ensure that all detail, especially lettering, is of such size as to be clearly legible when reduced to the final size. If he wishes, the author may insert lettering in pencil for re-draughting in this office.

If the scale is important, it should be shown on the figure, or, alternatively, the magnification or reduction may be stated in the caption, taking into account the printing reduction.

The figure number should not be given on the figure itself, only in the caption. Captions for all figures should be typed together at the end of the paper.

References

In the text, citations are to be by author's name and year, e.g. "(Brown, 1957)" or " . . . as stated by Brown (1957)". The list of references at the end of the paper is to be arranged in alphabetical order of author ' names. Titles of papers cited may be included or omitted; if included, all words other than conjunctions, pronouns, and prepositions are to have capital letters. Titles of periodicals are to be abbreviated in accordance with the "World List of Scientific Periodicals", 3rd ed. 1952. The title of the periodical and the volume (and part) number are to be underlined for italics, but not the page number(s). Titles of books are to be in inverted commas and not underlined; the name and location of the publisher are to be given. For arrangement, punctuation, etc., of references, see examples in this issue.

NEW ZEALAND JOURNAL OF SCIENCE

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THE MELOLONTHINAE (COLEOPTERA) OF NEW ZEALAND

DESCRIPTIONS OF NEW SPECIES, NOTES ON TYPES, AND A CATALOGUE

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(Received for publication, 11 March 1960)

INTRODUCTION

This paper is designed to bring systematic knowledge of the Melolonthinae of New Zealand up to date, while recognising that much material has yet to be collected, and much collected material is yet to be examined. However, a certain number of clear-cut species have recently been discovered and during 1954 it was possible to examine closely and prepare drawings from type material at the British Museum of Natural History. What is herein set out completes, on present-day standards, a basis on which future work may be conducted without perpetuation of fundamental taxonomic errors.

This paper should be used in conjunction with the author's revision of the group (Given, 1952).

ACKNOWLEDGMENTS

The production of this paper, both in the execution of investigations and in final preparation for publication would not have been possible, without the assistance and permission of the Trustees and Staff of the British Museum of Natural History. In particular, the author is indebted to Mr E. B. Britton of that institution for his advice and opinions whenever these have been sought. Grateful acknowledgment is made to collectors and institutions throughout New Zealand who have given or loaned material; no specimens requested have been withheld.

KEY TO GENERA OF NEW ZEALAND Melolonthinae

1. Antennae 9 – segmented ..... *Ocnodus Burm.*
   Antennae 8 – segmented 2
2. Metasternal process present 3
   Metasternal process absent 6
3. Large beetles not less than 12 mm. in length ..... *Chlorochiton* Arrow
   Small beetles less than 10 mm in length 4
4. Metasternal process in the form of a carina, not anteriorly produced 5
   Metasternal process strongly anteriorly produced ..... *Pyronota* Boisd.
5. Metasternal process anteriorly raised or angled ..... *Mycernus* Broun
   Metasternal process not anteriorly raised or angled ..... *Psilodontria* Broun
6. Elytral margins strongly flanged laterally; elytra fused medially ..... *Scythrodes* Broun
   Elytra not flanged or fused 7
7. Metasternum much longer than mesosternum 8
   Metasternum not longer than mesosternum ..... *Prodontria* Broun
8. Sternal surfaces without long silky hairs ..... *Sericospilus* Sharp.
   Sternal surfaces with long silky hairs 9
9. Alternate elytral interstices of equal width, uniformly punctate and not costate ..... *Odontria* White
   Alternate elytral interstices very narrow, non-punctate and raised as distinct costae ..... *Costelytra Giv.*

DESCRIPTIONS OF NEW SPECIES AND NOTES ON TYPE MATERIAL

NOTE—Comprehensive details of name changes, etc., are set out in the catalogue at the end of the paper.

Genus *Chlorochiton* Arrow

C. lineata (Arrow). (Figs 1–5)

Examination of the holotype male, from which the figures were drawn, shows that the material previously examined (Given, 1952) was correctly determined, any differences being within reasonable bounds of specific variation.

Other types examined were *C. suturalis* Fabr., *C. laevis* Arrow, *C. prasinus* (Broun), *C. longicornis* Arrow, *C. discoidea* (Broun) and *C. simmondsi* (Broun). *C. pulcher* (Broun) type has been previously examined.

Genus *Pyronota* Boisduval

P. festiva (Fabricius). (Figs 6–8)

The type in the Banks collection is a female. This collection also contains a paratype female. The colour is light green, suture brownish red, scutellum dark, thoracic median stripe present, lateral elytral stripes rather faint, reddish purple, ventral surface red-brown, legs somewhat lighter. Ventral vestitute white. Details of form of fore tibia, antenna and head are as figured.

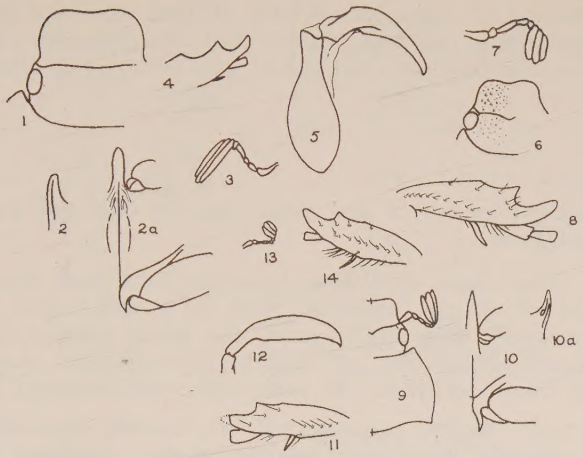


FIG. 1—*Chlorochiton lineata* (Arrow) type male; clypeal outline
FIG. 2—*Chlorochiton lineata* (Arrow) type male; metasternal process, lateral
FIG 2a—*Chlorochiton lineata* (Arrow) type male; metasternum
FIG. 3—*Chlorochiton lineata* (Arrow) type male; antenna
FIG. 4—*Chlorochiton lineata* (Arrow) type male; fore-tibial apex
FIG. 5—*Chlorochiton lineata* (Arrow) type male; parameres, lateral
FIG. 6—*Pyronota festiva* (Fabricius) type female; head
FIG. 7—*Pyronota festiva* (Fabricius) type female; antenna
FIG. 8—*Pyronota festiva* (Fabricius) type female; fore tibia
FIG. 9—*Pyronota lugubris* Sharp, Broun material; male; head and pronotum
FIG. 10—*Pyronota lugubris* Sharp, Broun material; male; metasturnum
FIG. 10a—*Pyronota lugubris* Sharp, Broun material; male; metasternal process, profile
FIG. 11—*Pyronota lugubris* Sharp, Broun material; male; fore tibia
FIG. 12—*Pyronota lugubris* Sharp, Broun material; male; parameres lateral
FIG. 13—*Pyronota lugubris* Sharp, Broun material; female; antenna
FIG. 14—*Pyronota lugubris* Sharp, Broun material; female; fore tibia

P. laeta (Fabricius) is represented in the Banks collection by the holotype female. This appears to be a variant of *P. festiva.*

The Broun type material of the genus was examined and is placed in correct relationship in the catalogue. The *P. lugubris* illustrated in Figs 9–14 is Broun material. Broun did not see Sharp's type and there is therefore no certainty that his determination was correct. Broun's *P. pallida* is a colour variant of his *lugubris.*

Genus *Costelytra* Given

This genus presents numerous problems at present and until much more collecting has been done, these problems cannot be satisfactorily solved. The range of known occurrence of the genus (apart from the species *zealandica* (White)) is extending year by year, but most new locality records are known from single specimens, no two of which appear identical.

The genotype, *C. zealandica* (White) has been examined and is identical with material as described (Given, 1952). *C. brunneum* (Broun) type material has also been seen and checks with Given 1952 description and figures.

C. diurna n.sp. (Figs 15–24)

The smallest species of the genus, and the only one known to be diurnal in flight.

Colour: Head black or piceous, pronotum black with testaceous areas towards lateral margins, scutellum black or piceous, elytra sub-metallic fumose testaceous with sutural stripe and lateral margins dark, almost black. Ventral surface and legs dark brown or piceous except for fore tibiae and femora which may be partly testaceous. Antennal club brown.

Head small, clypeus rugosely punctate, broadly rounded, obscurely truncate anteriorly, the margin strongly reflexed, depressed medially to the frontal suture. Frontal area rather coarsely punctate, particularly towards suture, but not rugose, somewhat flattened. Antennae (Fig. 16) similar in both sexes, segments 1–5 short, club rather broad and short. Palpi very short, not apically truncate. Labrum not prominent.

Pronotum not strongly produced at anterior angles, not strongly transverse. Punctation irregular, more coarse anteriorly than elsewhere.

Scutellum rather pointed posteriorly, irregularly punctate.

Elytra with punctures deeply impressed but rather sparse.

Fore tibiae (Fig. 18) not highly distinctive, rather bluntly toothed. Hind tibiae (Fig. 17) distinguished by the more or less complete row of strongly impressed setal bases below the tibial neck.

Vestitute moderately dense and long ventrally. Dorsally, long suberect bristles on the clypeus and anterior third of the pronotum, marginal bristles on pronotum and elytra and long decumbent hairs partly covering the scutellum.

Length: 7 mm – 9 mm.

Types: Holotype male and 58 paratypes in the collection of the Entomology Division, D.S.I.R., Nelson. Six paratypes in the collection of the British Museum (Natural History). All material was collected by Mr D. Wraight of the Department of Agriculture, Timaru, at the Gleniti golf links on 5 December 1955.

Remarks: The discovery of this species near Timaru is remarkable in view of the fact that the insect is day-flying and apparently congregates in conspicuous swarms. It is difficult to credit that a native insect of such conspicuous habits should for so long have remained undiscovered. In view of this, specimens were sent to Mr E. B. Britton of the British Museum (Natural History) who evidenced the opinion that the material was of the genus *Costelytra*, and not of Australian or other origin.

FIG. 15—*Costelytra diurna* n. sp. type male; parameres, posterior
FIG. 15a—*Costelytra diurna* n. sp. type male; parameres lateral
FIG. 16—*Costelytra diurna* n. sp. type male; antenna
FIG. 17—*Costelytra diurna* n. sp. type male; hind tibia
FIG. 18—*Costelytra diurna* n.sp. type male; fore tibia
FIG. 19—*Costelytra zealandica* (White) male; parameres, posterior
FIG. 19a—*Costelytra zealandica* (White) male; parameres, lateral
FIG. 20—*Costelytra zealandica* (White) male; antenna
FIG. 21—*Costelytra zealandica* (White) male; hind tibia
FIG. 22—*Costelytra zealandica* (White) male; fore tibia
FIG. 23—*Costelytra diurna* male; head and thorax
FIG. 24—*Costelytra zealandica* male; head and thorax
FIG. 25—*Ocnodus brookesi* (Broun) male; parameres, posterior
FIG. 25a—*Ocnodus brookesi* (Broun) male; parameres, lateral.
FIG. 26—*Ocnodus unidentatus* Lea (Australia) male; parameres, posterior
FIG. 26a—*Ocnodus undentatus* Lea (Australia) male; parameres, lateral
FIG. 27—*Odontria monticola* Broun, type female; head and pronotum
FIG. 28—*Odontria monticola* Broun, type female; antenna
FIG. 29—*Odontria monticola* Broun, type female; fore tibia
FIG. 30—*Odontria fusca* Broun, type male; parameres, lateral
FIG. 31—*Odontria fusca* Broun, type male; fore tibia
FIG. 32—*Odontria fusca* Broun, type male; antennal remnant
FIG. 33—*Odontria fusca* Broun, type male; pronotal outline
FIG. 34—*Odontria suavis* Broun, type male; parameres, lateral
FIG. 35—*Odontria suavis* Broun, type male; fore tibia
FIG. 36—*Odontria suavis* Broun, type male; head
FIG. 37—*Odontria rufescens* Given, type male; head
FIG. 38—*Odontria rufescens* Given, type male; fore tibia

Mr Wraight has informed the author that he located two swarms of beetles, one on the golf links, and another in an area sown in rape some two miles distant.

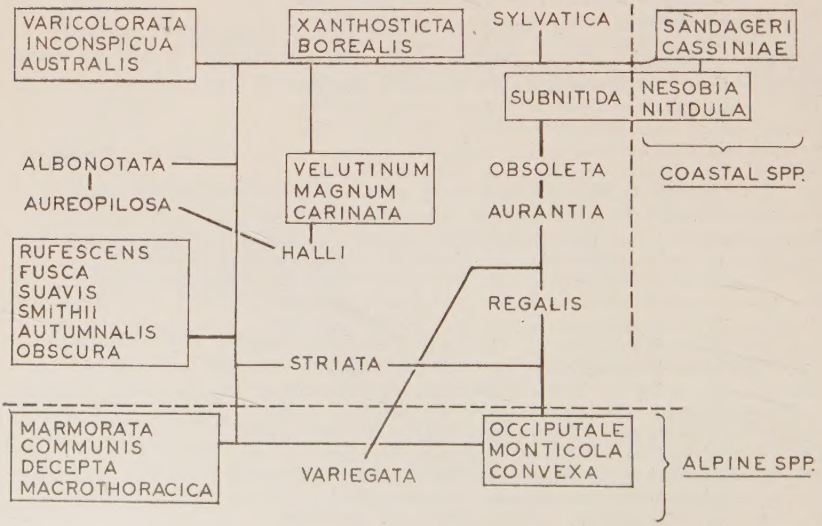
C. diurna is probably closest allied to *C. zealandica* (White), but is readily separated from this and other species of the genus by colour, antennal characters, hind tibiae, dorsal vestitute, punctation, and genital characters.

Genus *Odontria* White

All type material of this genus as now interpreted (Given, 1952) has been seen and examined. Several corrections have been made to the 1952 status of species and synonymy, and in at least one case the position rather than becoming clarified, has become somewhat confused and must await further collecting for final analysis (the *rufescens, fusca, suavis* complex). The *marmorata, convexa* etc. group and the *occiputale* complex still need further collection and study. These species groups, being variable infra-specifically and closely allied specifically cannot be reliably determined until long series from numerous localities have been studied.

A new key to this genus is needed but cannot be satisfactorily produced until both sexes of many species are available, and until the groups mentioned above have been clarified. The following table illustrates apparent relationships of species and species groups.

TABLE 1



O. monticola Broun. (Figs 27–29)

The author had previously considered this species to be synonymous with *O. striata* White (Given, 1952, p. 34). Examination of the type has, however, shown it to be a valid species very close to *O. regalis* Given. It is unfortunate that the type, which is at present unique, is a female.

The *O. fusca* complex. (Figs 30–38).

This complex appears to embrace *O. fusca, O. suavis, O. rufescens,* perhaps *O. smithii* etc. (see Table 1) and several other forms at present better left undescribed. Within this broad grouping, *O. suavis* and *O. rufescens* are so close that it is probable that further collection will collapse the latter species. Outside the group are species such as *O. variegata* and related undescribed forms which, with extended knowledge of variation and distribution, will almost certainly merge into the group. As at present known, the group may be split into three sections. *O. fusca* stands slightly apart on genital characters, *O. suavis* and *O. rufescens* group together with a number of undescribed forms, and *O. smithii, O. autumnalis, O. obscura* and several undescribed forms make up the third group. The entire group shows clinal tendencies which are becoming more pronounced with each season's collecting.

Two species in the Broun collection (British Museum, National History) which the writer tentatively associates with types of the opposite sex are illustrated in Figs 39–44. These are probably females of *O. inconspicua* Given and *O. aureopilosa* Given.

The type of *O. xanthostica* White is a female and is identical with material attributed to that species in New Zealand. Examination has shown that the following species fall into synonymy under *xanthosticta*: *O. piciceps* Broun, *O. punctulata* Broun, and *O. cinnamomea* Broun. This leaves the *O. piciceps* of the author (Given, 1952, p. 32) without a name. For this species as described in the work referred to above, the name *O. borealis* is proposed.

O. albonotata Broun (Figs 45–48) has now been identified with material from the vicinity of Rotorua and a good series is present in the collection of the Entomology Division, D.S.I.R., at Nelson.

O. obsoleta Broun (Figs 50–54) appears to fall between *O. aurantia* Given and *O. nitidula* Broun. However, *obsoleta* is moderately densely invested with long hairs whereas this is not the case with *aurantia* or *nitidula*. The pronotal vestiture is fur-like as in no other known species of the genus. The colour is dull light yellow-brown.

The type of *O. occiputale* is unfortunately a female but appears to be identical with material in New Zealand under the same name.

O. marmorata Broun (Figs 58–62) embraces *similis* Broun (Figs 63–66). Unfortunately, the type of *similis* is a female.

FIG. 39—*Odontria inconspicua* ? Given, female; head, lateral
FIG. 40—*Odontria inconspicua* ? Given, female; antenna
FIG. 41—*Odontria inconspicua* ? Given, female; fore tibia
FIG. 42—*Odontria aureopilosa* ? Given, female; head
FIG. 43—*Odontria aureopilosa* ? Given, female; antenna
FIG. 44—*Odontria aureopilosa* ? Given, female; fore tibia
FIG. 45—*Odontria albonotata* Broun, type male; head and pronotum
FIG. 46—*Odontria albonotata* Broun, type male; antenna
FIG. 47—*Odontria albonotata* Broun, type male; fore tibia
FIG. 48—*Odontria albonotata* Broun, type male; parameres, lateral
FIG. 49—*Odontria borealis* Given, type male; fore tibia
FIG. 50—*Odontria obsoleta* Broun, type male; pronotum
FIG. 51—*Odontria obsoleta* Broun, type male; head
FIG. 52—*Odontria obsoleta* Broun, type male; antenna
FIG. 53—*Odontria obsoleta* Broun, type male; parameres, lateral
FIG. 54—*Odontria obsoleta* Broun, type male; fore tibia
FIG. 55—*Odontria occiputale* Broun, type female; head
FIG. 56—*Odontria occiputale*, Broun, type female; antenna
FIG. 57—*Odontria occiputale* Broun, type female; fore tibia
FIG. 58—*Odontria marmorata* Broun, type male; pronotum
FIG. 59—*Odontria marmorata* Broun, type male; head
FIG. 60—*Odontria marmorata* Broun, type male; fore tibia
FIG. 61—*Odontria marmorata* Broun, type male; antenna
FIG. 62—*Odontria marmorata* Broun, type male; parameres, lateral
FIG. 63—*Odontria similis* Broun, type female; pronotum
FIG. 64—*Odontria similis* Broun, type female; head
FIG. 65—*Odontria similis* Broun, type female; antenna
FIG. 66—*Odontria similis* Broun, type female; fore tibia

Genus *Prodontria* Broun

Key to Species of the genus *Prodontria* Broun

1. Pronotum and elytra dull, invested with hairs 2
   Pronotum and elytra nitid, hairless or almost so 4
2. Vestiture dense and velvety. (Remarkables, Queenstown) ..... *P. pinguis* Giv.
   Vestiture not dense and velvety 3
3. Antennal club of male quadrilamellate, colour light, distinctly striate mottled. (Coastal areas, Southland) ..... *P. praelatella* (Broun)
   Antennal club of male trilamellate, the fifth segment produced but not equal to lamellate segments, colour dark, not distinctly mottled. (Snares Is.) ..... *P. longitarsis* (Broun)
4. Colour light brown, with or without darker suffusions 5
   Colour black or very dark 6
5. Colour uniform light brown. (Molyneux River, Cromwell) ..... *P. lewisii Broun*
   Colour light brown with darker suffusions on pronotum and elytra (Alexandra) ..... *P. bicolorata* Giv.
6. Elytra strongly striate 7
   Elytra obscurely striate 8
7. Elytra rather elongate with numerous whitish decumbent hairs. (Hunter Mts.) ..... *P. setosa* Giv.
   Elytra short with few hairs except at margins. (Manor Burn, Central Otago) ..... *P. modesta* (Broun)
8. Colour black, elytra glabrous (Old Man Range) ..... *P. capito* Broun
   Colour dark red-brown, elytra sparsely haired. (Lake Monowai) ..... *P. truncata* n. sp.

P. longitarsis (Broun). 1909 (Figs 67–72)

Examination of the type of this species in the Dominion Museum, Wellington, has clearly shown its affinity to *Prodontria* and it is therefore transferred from *Odontria*. The following descriptive notes with figures will serve to augment the original description of the species.

Colour: Dull red brown, legs shining and brighter in colour.

Head (Fig. 68) shining, sparsely, shallowly punctate.

Clypeus narrowly reflexed. Antennae as in Fig. 70.

Pronotum (Figs 67, 68) dull, finely punctate, vestitute short and decumbent, marginal bristles long. Scutellum finely punctate.

Elytra dull, characterised by irregular, shining, elongate strial punctures (Fig. 71) which do not bear bristles. Interspaces finely punctate and minutely transversely rugose with scattered larger punctures bearing elongate bristles.

Ventral surface invested with short hairs.

Fore-tibia and genital parameres as illustrated (Figs 72, 69).

Known only from the male holotype collected by G. V. Hudson at The Snares.

Length – 18 mm.

P. praelatella (Broun). (Figs 78–80).

The type of this species is identical with material identified in New Zealand from description.

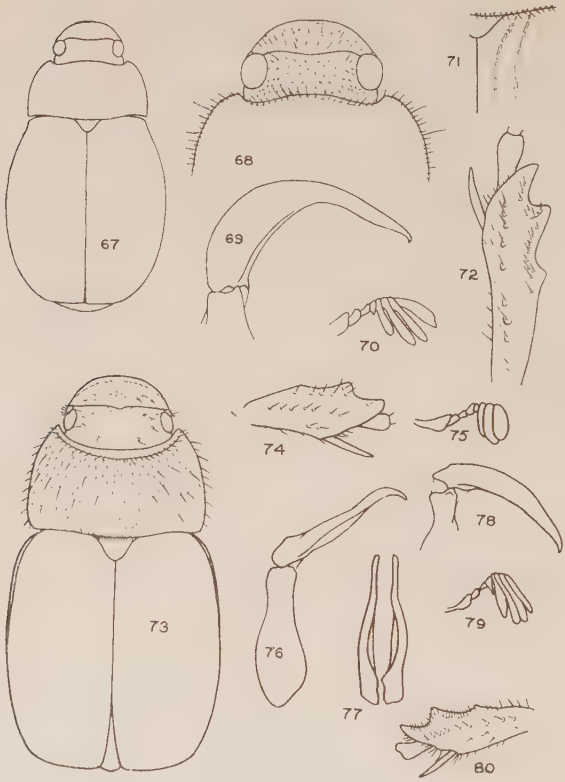


FIG. 67—*Prodontria longitarsis* (Broun), type male; dorsal
FIG. 68—*Prodontria longitarsis* (Broun), type male; head
FIG. 69—*Prodontria longitarsis* (Broun), type male; parameres, lateral
FIG. 70—*Prodontria longitarsis* (Broun), type male; antenna
FIG. 71—*Prodontria longitarsis* (Broun), type male; strial punctures
FIG. 72—*Prodontria longitarsis* (Broun), type male; fore tibia
FIG. 73—*Prodontria truncata* n. sp. type male; dorsal
FIG. 74—*Prodontria truncata* n. sp. type male; fore tibia
FIG. 75—*Prodontria truncata* n. sp. type male; antenna
FIG. 76—*Prodontria truncata* n. sp. type male; parameres, lateral
FIG. 77—*Prodontria truncata* n. sp. type male; parameres, posterior
FIG. 78—*Prodontria praelatella* (Broun) type male; parameres, lateral
FIG. 79—*Prodontria praelatella* (Broun) type male; antenna
FIG. 80—*Prodontria praelatella* (Broun) type male; fore tibia

P. truncata n. sp. (Figs 73–77).

Colour dark red-brown dorsally, somewhat lighter ventrally.

Head (Fig. 73) broad, rounded, sparsely haired. Clypeus broad and anteriorly uniformly rounded. Eyes small.

Pronotum (Fig. 73) moderately strongly transverse, vestiture as illustrated. Posterior angles rounded, anterior angles moderately prominent.

Elytra short, markedly truncate, strongly convex. Vestiture (not illustrated) about as dense as on pronotum.

Fore-tibiae, antennae, and genitalia as illustrated (Figs 74–77).

Length – 11 mm.

Type: Holotype male, collected by Mr D. Tuart near Lake Monowai about December 1956, in the collection of the Dominion Museum, Wellington. The specimen was submitted for description by Mr G. Ramsay.

Remarks: This species is allied to *P. capito* Broun, but may be distinguished by the presence of dorsal vestitute, less convex and compact form and lighter colour.

Genus *Sericospilus* Sharp

It is unfortunate that the genotype (*S. advena* Sharp) has not been examined.

An examination of the type of *S. rossii* (White) (Figs 93, 94) shows this species to be allied to *S. brevis* Given and *S. minor* Given. In fact, the last two species may be better placed in subspecific status under *rossii*. A specimen in the Broun collection labelled as *rossii* (Figs. 95, 96) is also close but is even closer to *minor*.

S. costella (Broun) type (Figs 84–86) is in general appearance close to *aenealis* (Broun), but differs from that species markedly in genitalia. Differences in external structure (pronotal outline, less strongly reflexed clypeal margin and minor antennal differences) could be considered as sub-specific.

The type of *S. eximia* (Broun) (Figs 87, 89, 91) is similar to *S. truncatus* Given, differing as illustrated in relative antennal size, truncation of elytra, ultimate fore-tarsal segment and genital parameres.

The type of *S. aenealis* (Broun) is exactly as illustrated previously (Given, 1952).

Sericospilus ornatus n. sp. (Figs 81–83)

Colour: Iridescent testaceous dorsally with darker suffusions on head and thorax and sooty black strial patches on elytra, testaceous ventrally.

Form slender, similar to *aenealis* and *costella*.

Clypeus (Fig. 81) anteriorly incurved, with anterior and lateral margins strongly reflexed. Antennae of male (Fig. 82) with four equal lamellae, the fourth segment not modified.

Pronotum broadest posteriorly, anterior angles acute and prominent, posterior angles rectangular.

Elytra very elongate, otherwise not characteristic.

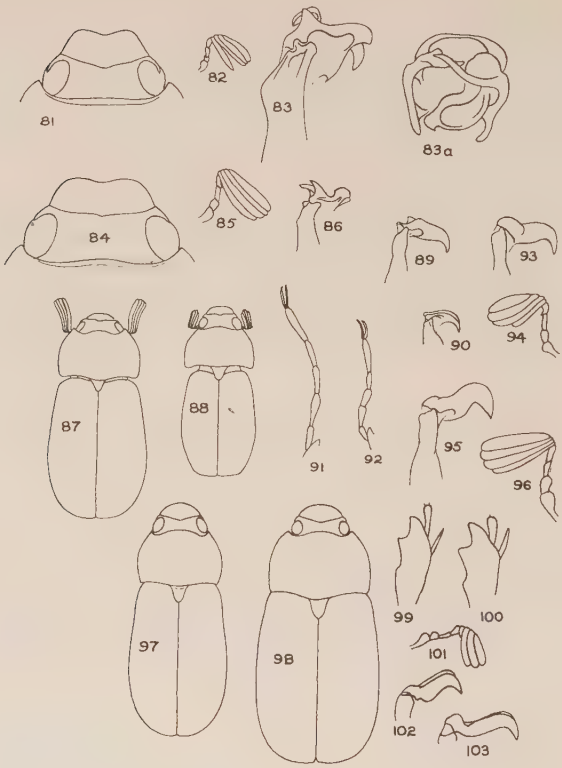


FIG. 81—*Sericospilus ornatus*, n. sp. type male; head
FIG. 82—*Sericospilus ornatus*, n. sp. type male; antenna
FIG. 83—*Sericospilus ornatus*, n. sp. type male; parameres, lateral
FIG. 83a—*Sericospilus ornatus*, n. sp. type male; parameres, posterior
FIG. 84—*Sericospilus costella* (Broun), type male; head
FIG. 85—*Sericospilus costella* (Broun), type male; antenna
FIG. 86—*Sericospilus costella* (Broun), type male; parameres, lateral
FIG. 87—*Sericospilus eximia* (Broun), type male; dorsal
FIR. 88—*Sericospilus truncatus* Given, type male; dorsal
FIG. 89—*Sericospilus eximia*, type male; parameres, lateral
FIG. 90—*Sericospilus truncatus*, type male; parameres, lateral
FIG. 91—*Sericospilus eximia*, type male; fore tarsus
FIG. 92—*Sericospilus truncatus*, type male; fore tarsus
FIG. 93—*Sericospilus rossii* (White), type male; parameres, lateral
FIG. 94—*Sericospilus rossii* (White), type male; antenna
FIG. 95—*Sericospilus rossii* (according to Broun), male; parameres, lateral
FIG. 96—*Sericospilus rossii* (according to Broun), male; antenna
FIG. 97—*Sericospilus watti* n. sp. type male; dorsal
FIG. 98—*Sericospilus glabrata* (Broun), male; dorsal
FIG. 99—*Sericospilus watti*, type male; fore tibia
FIG. 100—*Sericospilus glabrata*, male; fore tibia
FIG. 101—*Sericospilus watti*, type male; antenna
FIG. 102—*Sericospilus watti*, type male; parameres, lateral
FIG. 103—*Sericospilus glabrata*, type male; parameres, lateral

Ultimate fore tarsal segment considerably longer than penultimate.

Length: 11 mm.

Type: Male collected by Dr R. A. Cumber, Waipoua Forest, 21 January 1957, in the collection of the Entomology Division, D.S.I.R., Nelson.

No other specimens known.

Remarks: In general appearance, this species resembles *costella* (Broun) and *aenealis* (Broun). However, it may be separated from *costella* on the form of the fourth antennal segment (Figs 82, 85) and the clypeal outline (Figs 81, 84). From *aenealis* it may readily be distinguished by the relatively long ultimate segment of the fore tarsus, which is little if any longer than the penultimate one in *aenealis*. Pronotal outline and antennal characters also distinguish it from *aenealis* and the fact that the pronotum is broadest about the middle in *aenealis*, and broadest between the posterior angles in *ornatus* may also assist in separation.

Sericospilus watti n. sp. (Figs 97, 99, 101, 102).

A small slender glabrous species, closely allied only to *S. glabrata* (Broun).

Colour: Dark brown dorsally, darker areas suffused on discal areas of head and pronotum, ventral surface and legs lighter.

Head with clypeus strongly depressed and finely punctate-rugulose, frons finely punctate but not rugulose. Antenna of male tri-lamellate, club short. Labial palpi apically truncate.

Pronotum (Fig. 97) definitely narrowed posteriorly, not strongly transverse, anterior angles acute.

Elytra (Fig. 97) elongate, parallel-sided.

Male genitalia (Fig. 102) similar to those of *S. glabrata*, but with parameres less slender and more sharply pointed.

Length: 8 mm. Breadth: 3 mm.

Type: Collected by Mr J. C. Watt, Mt Hobson, Gt Barrier Island, 20 November 1954. In the collection of Mr J. C. Watt.

Remarks: This species is the only one except *S. glabrata* (Broun) in the genus with a tri-lamellate antennal club in the male. From *glabrata* it differs in being smaller, more slender, in having the pronotum narrowed posteriorly (Figs 97, 98), somewhat more slender fore tibia and less slender male genital parameres (Figs 102, 103). Antennae and colour are almost identical in the two species.

Genus *Ocnodus* Burmeister (Figs 25, 26)

The genus *Xylostygnus* Broun has been considered for some time to be inconsistent with the New Zealand melolonthid fauna. Being entirely coastal, it was thought to have originated as a possible wanderer of relatively recent times from Australia. This has proved almost certainly to be the case and *Xylostygnus* is now submerged beneath the Australian genus *Ocnodus*.

Figures 26 and 27 illustrate fundamental similarities of structure in genital parameres between Australian and New Zealand species. These basic similarities are clearly seen in all aspects of material from the two countries. This is the only melolonthid genus in New Zealand having 9-segmented antennae and is the only genus of the subfamily common to Australia and New Zealand.

REFERENCE

GIVEN, B. B. 1952: *Bull. N.Z. Dep. sci. industr. Res. 102.*

CATALOGUE OF THE MELOLONTHINAE OF NEW ZEALAND

Family SCARABAEIDAE

Subfamily MELOLONTHINAE

Tribe SERICINI Dalla Torre, 1912, Coleopt. Cat. 45, Scarabaeidae: Melolonthinae, *1*:8. (Britton, 1957, A Revision of the Australian Chafers (Coleoptera: Scarabaeidae: Melolonthinae), *1*:9.)

Genus ***Mycernus*** Broun, 1904
Ann. Mag. nat. Hist. (7) *14*:52
Genotype: *Mycernus Elegans* Broun, 1904.
elegans Broun, 1904. Ann. Mag. nat. Hist. (7) *14*:52
Intermediatus Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:74

Genus ***Psilodontria*** Broun, 1895
Ann. Mag. nat. Hist. (6) *15*:200
Genotype: *Psilodontria Viridescens* Broun, 1895.
viridescens Broun, 1895. Ann. Mag. nat. Hist. (6) *15*:201

Tribe XYLONYCHINI Britton, 1957, A Revision of the Australian Chafers (Coleoptera: Scarabaeidae: Melelonthinae) *1*:9.

Genus *Chlorochiton* Arrow, 1903
Ann. Mag. nat. Hist. (7) *2*:305
Neostethaspis Dalla Torre, 1912. Cat. Coleopt. *47*:89
Melolontha (Part) Fabricius, 1775. Syst. Ent. : 31
Rutela (Part) Schoenherr. 1817. Syn. Insect. *1* (3); 149
Micronyx Boisduval, 1835. Voy. de L'Astrolabe, Coleopt. : 188 (Not Schoenherr, 1833)
Rutele Boisduval, 1835. Op. cit., Atlas
Stethaspis Hope, 1837. Coleopt. Man. *1*:104
Paranonca Castelnau, 1840. Hist. Nat. Coleopt. *2*:143
Costleya Broun, 1893. Man. N.Z. Coleopt. *5*:1115
Poecilodiscus Broun, 1895. Ann. Mag. nat. Hist. (6) *16*:201
Genotype: *Melolontha Suturalis* Fabricius, 1775.

convexa Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:94
discoidea (Broun), 1893. Man. N.Z. Coleopt. *5*:1116 (*Costleya*).
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:96 (Chlorochiton)
intermediata Given, 1952. ibid.:95
lineata (Arrow), 1924. Ann. Mag. nat. Hist. (9) *13*:553 (*Costleya*)
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:97 (*Chlorochiton*)
longicornis Arrow, 1924. Ann Mag. nat. Hist. (9) *13*:550
prasinus (Broun), 1893, Man. N.Z. Coleopt. *5*:1115 (*Stethaspis*)
Arrow, 1903. Ann. Mag. nat. Hist. (7) *11*:305 (Chlorochiton)
Dalla Torre, 1912. Coleopt. Cat. *47*:89. (*Neostethaspis*)
planiclypeus Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:94.
pulcher (Broun), 1895. Ann. Mag. nat. Hist. (6) *15*:205. (*Poecilodiscus*)
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:96 (Chlorochiton).
simmondsi (Broun), 1893. Man. N.Z. Coleopt. *5*:1115. (*Costleya*)
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:98 (Chlorochiton).
suturalis (Fabricius), 1775. Syst. Ent. : 34. (*Melolontha*).
Schoenherr, 1817. Syn. Insect. *1* (3):150. (*Rutela*)
Hope, 1837. Coleopt. Man. *1*:104. (*Stethaspis*).
Arrow, 1903. Ann. Mag. nat Hist. (7) *11*:305. (*Chlorochiton*)
chlorophyllus Boisduval, 1835. Voy de l'Astrolabe, Coleopt. :189. (*Micronyx*).
chlorophylle Boisduval, 1835. ibid., Atlas (*Rutele*).
laevis Arrow, 1924. Ann. Mag. nat. Hist. (9) *13*:551.

Genus ***Pyronota*** Boisduval, 1835.
Voy. de l'Astrolabe, Coleopt. :213.
Melolontha (Part) Fabricius, 1775. Syst. Ent. : 36.
Rutela (Part) Schoenherr, 1817. Syn. Insect *1* (3):149
Calonota Hope, 1837. Coleopt. Man. *1*:107
Dalla Torre, 1912. *Coleopt.* Cat. *47*:90
Genotype: *Melolontha Festiva* Fabricius, 1775.
edwardsi Sharp, 1876. Ent. mon. Mag. *13*:72
Dalla Torre, 1912. Coleopt. Cat. 47:90. (*Calonota*).
dives Broun, 1893. Man. N.Z. Coleopt. *5*:1117
Var. A. Given. 1952. Bull. N.Z. Dep. sci. industr. Res. 102:78
Var. B. Given, 1952 ibid. : 79.
Var. C. Given, 1952. ibid. :79.
Var. D. Given, 1952. ibid. :79.
festiva (Fabricius), 1775. Syst. Ent. : 36. (*Melolontha*).
Schoenherr, 1817. Syn. Insect. *1* (3):153. (*Rutela*).
Hope, 1837. Coleopt. Man. *1*:74, 107. (*Calonota*).
Boisduval, 1835. Voy de l'Astrolabe, Coleopt. : 213. (*Pyronota*).
Dalla Torre, 1912. Coleopt. Cat. *47*:90 (Calonota).
laeta Fabricius, 1775. Syst. Ent. :36 (*Melolontha*).
electa Broun, 1893. Man. N.Z. Coleopt. *5*:1116.
regalis Broun, 1893. ibid. : 1116
aurata Broun, 1893, ibid. : 1117
purpurata Broun, 1893. ibid. : 1117
caerulea Broun, 1893. ibid. : 1117

inconstans Brookes, 1926. Trans. N.Z. Inst. *56*:444
Var. A. Given, 1952. N.Z. Dep. sci. industr. Res. *Bull. 102*:80
lugubris Sharp, 1876. Sci. Trans. R. Dublin Soc., *3* (2):398.
Dalla Torre, 1912. Coleopt. Cat. *47*:90 (*Calonota*).
minor Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:81
munda Sharp, 1876. Ent. mon. Mag. *13*:73
Dalla Torre, 1912. Coleopt. Cat. *47*:90 (*Calonota*).
pallida Broun, 1893. Man. N.Z. Coleopt. *5*:1118
punctata Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:83.
rubra Given, 1952. ibid. : 82
setosa Given, 1952. ibid. : 81.
sobrina Sharp, 1876. Ent. mon. Mag. *13*:73.
Dalla Torre, 1912. Coleopt. Cat. *47*:91 (Calonota).
splendens Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:83

Tribe COLPOCHILINI Britton, 1957. A revision of the Australian Chafers (Coleoptera: Scarabaeidae: Melolonthinae) *1*:*10*

Genus ***Costelytra*** Given, 1952.
Bull. N.Z. Dep. sci. industr. Res. *102*:13
Rhisotrogus White, 1846. Voy. Erebus and Terror, Zool., Insects:10 (Not Latreille, 1829).
Odontria Blanchard, 1850. Mus. d'hist. Nat. Paris.
Cat. Coll. Ent., Coleopt. *1*:106. (Not White, 1846).
Genotype: *Rhisotrogus Zealandicus* White, 1846.
austrobrunneum Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:17.
brunneum (Broun), 1880. Man. N.Z. Coleopt. *1*:270. (*Odontria*).
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:16 (*Costelytra*).
macrobrunneum Given, 1952. ibid. : 17
piceobrunneum Given, 1952. ibid. : 18.
pseudobrunneum Given, 1952. ibid. : 19
zealandica (White), 1846. Voy. Erebus and Terror, Zool., Insects : 10 (*Rhisotrogus*).
Blanchard, 1850. Mus. d'hist. Nat. Paris, Cat Coll. Ent., Coleopt. *1*:106. (*Odontria*).
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:14 (*Costelytra*).
castanea Blanchard, 1850. Mus. d'Hist. Nat. Paris Cat. Coll. Ent. Coleopt. *1*:107. (*Odontria*).
diurna n.sp.

Genus ***Odontria*** White, 1846.
Voy. Erebus and Terror, Zool., Insects : 10
Genotype: *Odontria Striata* White, 1846.
albonotata Broun, 1893. Man. N.Z. Coleopt. *5*:1118
aurantia Given, 1952. Bull N.Z. Dep. sci. industr. Res. *102*:47
aureopilosa Given, 1952. ibid. : 34
australis Given, 1952. ibid. : 36.
autumnalis Given, 1952. ibid. : 37.
carinata Given, 1954. Rec. Auckland (N.Z.) Inst. *4* (5):269
cassiniae Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:29

communis Given, 1952. ibid : 42.
convexa Given, 1952. ibid. : 42.
decepta Given, 1952. ibid. : 44.
fusca Broun, 1893. Man. N.Z. Coleopt. 7 :1452.
halli Broun, 1921. Bull. N.Z. Inst. *1* (6) :533.
inconspicua Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102* :33
macrothoracica Given, 1952. ibid. : 45.
magnum Given, 1952. ibid. : 27
marmorata Broun, 1893. Man. N.Z. Coleopt. 7 :1451
    similis Broun, 1912. Trans. N.Z. Inst. *44* :427
monticola Broun, 1912. Trans. N.Z. Inst. *44* :426.
    Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102* :34. (Syn. of *striata*)
nesobia Broun, 1912. Bull. N.Z. Inst. *1* (7) :615.
nitidula Broun, 1911. Trans. N.Z. Inst. *44* :425.
obscura Broun, 1895. Ann. Mag. nat. Hist. (6) *15* :203
obsoleta Broun, 1917. Bull. N.Z. Inst. *1* (5) :390.
occiputale Broun, 1893. Man. N.Z. Coleopt. 7 :1451.
    epomeas Lewis, 1903. Trans. N.Z. Inst. *35* :272.
regalis Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102* :48
rufescens Given, 1952. ibid. : 40
sandageri Broun, 1881. Man. N.Z. Coleopt. *2* :929.
smithii Broun, 1893. ibid. 7 :1450.
striata White, 1846. Voy. Erebus and Terror, Zool., Insects : 10
suavis Broun, 1880. Man. N.Z. Coleopt. *1* :266
subnitida Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102* :26
sylvatica Broun, 1880. Man. N.Z. Coleopt. *1* :268.
    puncticollis Broun, 1915. Bull. N.Z. Inst. *1* (4) :317.
    calvescens Brookes, 1926. Trans. N.Z. Inst. *56* :445.
varicolorata Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102* :35.
variegata Given, 1952. ibid. : 47
velutinum Given, 1952. ibid. : 30
xanthosticta White, 1846. Voy. Erebus and Terror, Zool. Insects : 10
    cinnamomea White, 1846. ibid. :10
    punctulata Broun, 1880. Man. N.Z. Coleopt. *1* :266.
    piciceps Broun, 1893. ibid. 71450 (Not Given, 1952)
borealis (new name) Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102* :32 (piciceps) (Not Broun, 1893)

Genus ***Prodontria*** Broun, 1904.
Ann. Mag. nat. Hist. (7) *14* :53
Odontria (Part) Broun, 1909. Ann. Mag. nat. Hist. (8) *3* :400 Not White, (1896)
Lewisiella Broun, 1909. Ann. Mag. nat. Hist. (8) *3* :398
Genotype: *Prodontria* Lewisii Broun, 1904.
bicolorata Given, 1952. Bull. N.Z. Dept. sci. industr. Res. *102* :58.
capito (Broun), 1909. Ann. Mag. nat Hist. (8) *3* :400 (*Lewisiella*)
    Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102* :58. (*Prodontria*).
lewisii Broun, 1904. Ann. Mag. nat. Hist. (7) *14* :54
longitarsis (Broun), 1909. Subantarctic Isls. N.Z. *1* :105. (*Odontria*)

modesta (Broun), 1909, Ann. Mag. nat. Hist. (8) *3*:399 (*Lewisiella*)
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:57. (*Prodontria*).
pinguis Given, 1952. ibid. : 56
praelatella (Broun), 1909. Ann. Mag. nat. Hist. (8) *3*:400. (*Odontria*)
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:55 (*Prodontria*)
setosa Given, 1952. ibid. : 59.
truncata n. sp.

Genus sericospilus Sharp, 1882.
Trans ent. Soc. Lond. 1882:83
Eusoma White, 1846. Voy. Erebus and Terror, Zool. Insects : 10
Odontria (Part) Broun, 1880. Man. N.Z. Coleopt. *1*:268 (Not White, 1846)
Genotype: *Sericospilus Advena* Sharp, 1882
advena Sharp, 1882, Trans. ent. Soc. Lond. 1882:84
aenealis (Broun), 1909. Ann. Mag. nat. Hist. (8) *3*:397 (*Eusoma*).
Dalla Torre, 1912. Coleopt. Cat. *47*:128. (*Odontria*).
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:62 (*Sericophilus*).
Var. A. Given, 1952. ibid. : 63.
Var. B. Given, 1952. ibid. : 63.
Var. C. Given, 1952. ibid. : 63.
Var. D. Given, 1952. ibid. : 63.
brevis Given, 1952. ibid. : 65.
costella (Broun), 1880. Man. N.Z. Coleopt. *1*:268. (*Odontria*).
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:68. (*Sericospilus*).
cumberi Given, 1952. N.Z. Ent. *1* (3):19.
eximia (Broun), 1917. Bull. N.Z. Inst. 1. (5):380. (*Eusoma*).
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:69. (*Sericospilus*).
glabrata (Broun), 1893. Man. N.Z. Coleopt. 7:1452. (*Odontria*).
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:67. (*Sericospilus*).
intermediatus Given, 1952. ibid. : 63
minor Given, 1952. ibid. : 66.
obscura Given, 1952. ibid. : 66.
piliventris (Broun), 1921. Bull. N.Z. Inst. *1* (6); 61 (*Eusoma*).
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:64. (*Sericospilus*).
rossii (White), 1846. Voy. Erebus and Terror, Zool., Insects: 10 (*Eusoma*).
Broun, 1880. Man. N.Z. Coleopt. *1*:268. (*Odontria*).
Given, 1952. Bull. N.Z. Dep. sci. industr. Res. *102*:68. (*Sericospilus*).
truncatus Given, 1952. ibid. : 64.
watti n. sp.
ornatus n. sp.

Genus ***Scythrodes*** Broun, 1886.
Man. N.Z. Coleopt. *4*:955.
Genotype: *Scythrodes Squalidus* Broun, 1886.
squalidus Broun, 1886. Man. N.Z. Coleopt. *4*:955.

Tribe SCITALINI Britton, 1957, A Revision of the Australian Chafers (Coleoptera: Scarabaeidae: Melolonthinae) *1*:10.

*Genus ***Ocnodus*** Burmeister, 1855.
Handbk. Ent. *4* (2) :208.
Xylostygnus Broun, 1881. Man. N.Z. Coleopt. 4:956.
Genotype: *Ocnodus Decipiens* Burmeister, 1855. (Australia).
brookesi (Broun), 1921, Bull. N.Z. Inst. *1* (6) :534. (*Xylostygnus*)
piceus (Broun), 1881. Man. N.Z. Coleopt. *4*:956. (*Xylostygnus*)

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*The genus *Ocnodus* is here accepted in the sense used by Blackburn, 1907. Trans. roy. Soc. S. Austr. *31*:277.

THREE WATERWEEDS OF THE FAMILY HYDROCHARITACEAE IN NEW ZEALAND

By R. MASON, Botany Division, Department of Scientific and Industrial Research, Christchurch

(Received for publication, 15 March 1960)

Summary

Two new adventive species are recorded: *Lagarosiphon major* (Ridley) Moss and *Egeria densa* Planch. Descriptions of these and an account of their distribution are given together with comparative data for the long-established *Elodea canadensis,* Michx.

INTRODUCTION

One member of the tribe Anachariteae of the family Hydrocharitaceae, *Elodea canadensis,* has long been established in New Zealand and is now well known and widespread here. Since 1946 a few collections have been made of two other species of the same tribe, *Egeria densa* and *Legarosiphon major.* In the course of a field trip in the Waikato late in 1958 it became apparent that these two species were well established in the district, growing in some waters almost to the exclusion of other aquatic plants. As the information in the few published statements concerning the distribution of *Elodea canadensis* in New Zealand does not conform very well with what has been seen in the field in recent years, and as all three weeds are somewhat of a nuisance and may spread further, it seems worthwhile to record their occurrence at the present day and their history here as far as it is known.

During the last ten years some districts have been well explored for aquatic plants, but much country still remains in which they have never been collected or collected only casually. (See Fig. 1.) The visit to the Waikato took place between 17 November and 14 December 1958. The ground covered was that of the valleys of the Waikato and Waipa rivers and their tributaries north of a line from Te Kawa to the head of Arapuni Lake. The main rivers, the streams, drains, bogs, and swamps, and most of the lakes were visited.

Trips were also made south of Port Waikato as far as Kaawa Creek and to Raglan from Hamilton by way of Whatawhata and back through Waingaro and Glen Murray.

KEY

The three plants may be distinguished in the vegetative condition by means of the following key:

1. Leaves alternate, recurved, stiff ..... *Lagarosiphon major*
   Leaves in whorls, not recurved, lax 2
2. Leaves in whorls of 2–3, 5–12 mm long ..... *Elodea canadensis*
   Leaves in whorls of 4–5, 11–30 mm long ..... *Egeria densa*

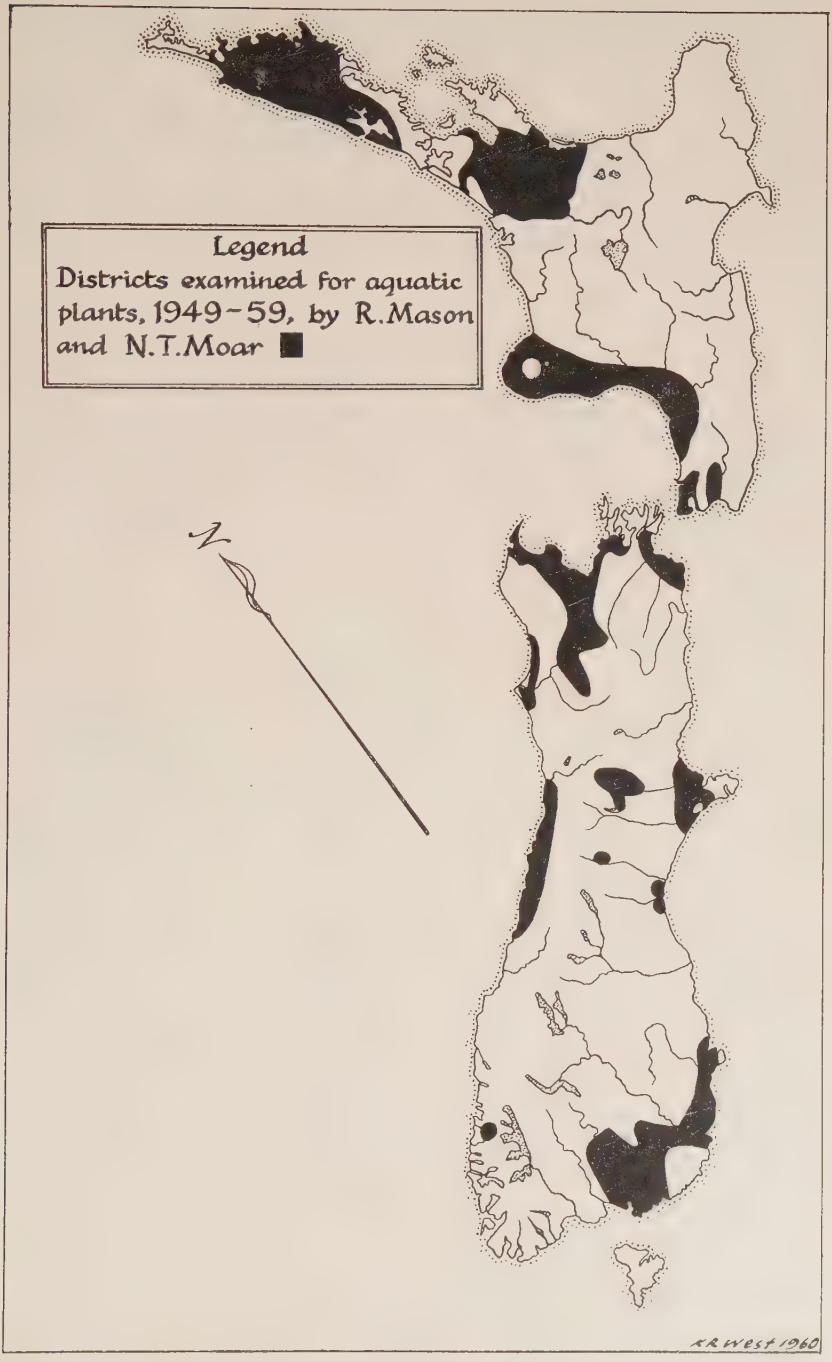
Legend
Districts examined for aquatic plants, 1949–59, by R. Mason and N. T. Moar
N
K R West 1960

FIG. 1

All three are dioecious, submerged herbs, with long, slender, branched stems arising from creeping stems. The stems are set about with pellucid, narrow, rather obscurely serrated leaves.

Specimens cited are in the Herbarium of the Botany Division, D.S.I.R., Christchurch unless otherwise indicated. AK indicates Auckland Museum.

Elodea canadensis Michx., Fl. Bor. Am. 1:20 1803

Anarcharis canadensis (Michx.), Planch. Ann. Sci. Nat. Bot. Ser. III 11:75 1849.

Anacharis Alsinastrum Babington, Ann. Sci. Nat. Bot. Ser. III 11:69 1848.

Stems brittle, about 1 mm in diam., leaves in whorls of 2–3 (only 3 in N.Z.), 4–14 mm long by 2–4 mm wide, oblong or ovate-oblong, obtuse; male spathe one-flowered; male flowers on peduncles up to 20 cm long, sepals 3, greenish with purple spots, edges hyaline, petals 3; female flowers with long perianth tube up to 20 cm long, *c.* 5 mm in diam., sepals 3, petals 3, staminodes 3, pistils 3, petaloid, purple, strongly emarginate (Fig. 2). Only pistillate plants have been found in New Zealand.

Egeria densa *Elodea canadensis* *Lagarosiphon major*

FIG. 2

Commonly known as oxygen weed in the Auckland Province, as blackweed, Yankee weed, riverweed, and California weed in Canterbury; also as Elodea and Canadian waterweed.

GENERAL DISTRIBUTION: Canada and the United States. Naturalised in Europe and Great Britain, Tasmania, and New Zealand.

NEW ZEALAND DISTRIBUTION: North Island – near Kaitaia*; south of Auckland to Cook Strait but apparently absent in Taranaki and the west of Wellington north of the Rangitikei River.

South Island: on eastern side; near lakes Mahinapua (Hokitika) and Manapouri. Sea level to 2,300 ft. (Fig. 3.)

SPECIMENS SEEN: Muir's Lake, Waiuku, *N. T. Moar 444*; Waikato River near elbow, *B. E. G. Molesworth*, 10.2.1946 (AK); near Te Kohanga, Lower Waikato River, *R. Mason & N. T. Moar 6122*; N.E. corner of Lake Whangape. *Mason & Moar 6283;* main drain from Lake Whangape, Raglan Co., *Mason & Moar 6354;* Waikato River, landing between Huntly and Ohinewai, *Mason & Moar 6801;* Waikato River, south of Huntly, *Mason & Moar 6332*; Waikato River, ½ mile N. of Ngaruawahia, *Mason & Moar 6339*; Waikato River, at Ngaruawahia, *Mason & Moar 6794*; Waipa River at end of Collie's Road, Waipa Co., *Mason & Moar 6456*; Hamilton, *H. H. Allan* 22.7.1937; Karapiro Lake, near bridge, *Mason & Moar 6515*; Lake Karapiro, *P. Hynes,* 15.12.1952 (AK); Waitakaruru Stream Canal, Hauraki Plains, *Mason 7180*; Waitakaruru River, *Mason 7197*; Waihou [Thames] River at Pukahu Road, *Mason 7337;* Waihou River, about 3 miles W. of Paeroa, *Mason 7439*; Waihou River at Tirohia, *Mason 7440*; Waihou River at Te Aroha, *Mason 7546*; Waihou River near Manawaru, *Mason 7587*; Waihou River about 2 miles from Tirau, *Mason 7602*; Waihou River about 2 miles E. of Putaruru, *Mason 7634*; Kaituna River, Bay of Plenty, *Mason 7674*; Mangaone Stream, *I. W. Davey,* 24.3.1937; Palmerston North, *Mason 4350*; Makerua, *Mason 4369*; Waipoua River, Masterton, *V. D. Zotov,* 2.2.1945; near Featherston, *K. W. Allison* 1916 (AK); north of Martinborough, *A. J. Healy 50/16*; Woburn, Hutt Valley, *Mason 2592*; Waiwhetu stream, Hutt Valley, *A. P. Druce,* June 1959; Te Paru, Pelorus Sound, *A. J. Healy,* 18.11.1942; Opawa River, Blenheim, *Mason 3125*; Lower Wairau River, Marlborough, *Mason 3886*; Lake Mahinapua, Westland, *Mason & Moar 5206*; 1½ miles N.W. of Fernside, Canterbury, *Mason 7117*; Avon, Canterbury, no date, *T. F. Cheeseman* (AK); near Christchurch, no date, *T. Kirk*; Avon, Christchurch, no collector or date; Lake Camp, Canterbury, *Mason 4389*; Washdyke, Canterbury, *Mason,* 17.10.1948; Washdyke, *Mason,* 17.10.1948; Timaru, *Mason,* 27.1.1945; Lake Manapouri near Spey Hut, *M. J. A. Simpson 1301*; Lakeside Road, Balclutha, *Mason & Moar 963*; Inchclutha, *Mason & Moar 980*; Mataura River, *Mason & Moar 1098*; Waiki-iwi Stream, near Oreti, Southland, *Mason & Moar 1229.*

*Recorded by Cheeseman (1925) as having been found by R. H. Matthews. The specimens could not be found in the Auckland Museum in 1954 and may not have been kept by Cheeseman.

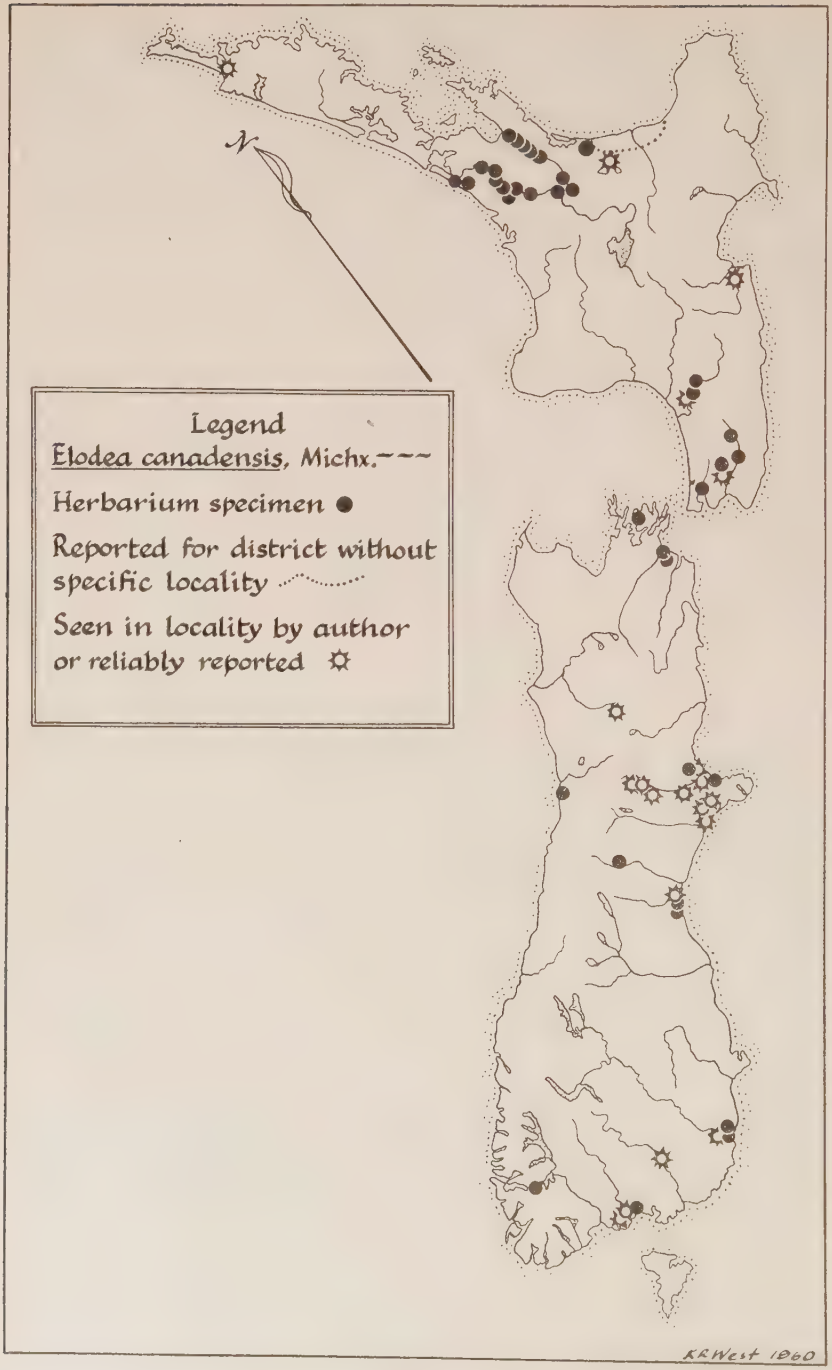
N
Legend
Elodea canadensis, Michx.~~~
Herbarium specimen ●
Reported for district without specific locality
Seen in locality by author or reliably reported ☼
K.R.West 1960

FIG. 3

Elodea canadensis was brought from Tasmania at various times in water containing perch, tench, and goldfish (Thomson 1922). According to Armstrong (1872) it was first brought to New Zealand in 1868 and planted in a pond in Christchurch as a shelter for young trout; it soon became established in the Avon and, at the time of his writing, was spreading there with astonishing rapidity. At the present day it is one of the most abundant of the weeds that have to be regularly cleared from the drains in Canterbury.

E. canadensis is one of those weeds which spread with alarming vigour when first naturalised, and later become less vigorous. In the British Isles, shortly after first becoming established, it caused alarm by the manner in which it choked waterways, impeded drainage, prevented fishing, rowing, and swimming, and hindered the towing of barges. After some years the growth became less luxuriant and sixty-seven years after its first recorded appearance it displayed no greater luxuriance than any other water plant with which it was associated (Arber 1920). Today it is "widespread but seldom abundant" (Clapham *et al.* 1952). Nevertheless Elton (1958) states, "No one could claim that the Canadian waterweed, *Elodea canadensis*, that spread throughout Great Britain in the last century had been brought under control by man".

So far as is known *E. canadensis* has not been as aggressive or so fast spreading in New Zealand as in England in spite of its initially rapid spread in this country. Cheeseman (1920), when recording it for Featherston, said, "Considering how rapidly this plant increased when first introduced into Britain, it is somewhat remarkable that its spread in New Zealand has been so slow since its first introduction in 1870". In 1906, 38 years after its introduction, Cheeseman had given only three districts for it: Mangonui, the Bay of Plenty, and the Canterbury Plains. In 1922 Thomson said it "is now abundant throughout New Zealand". Judging by its distribution as known at present, if Cheeseman perhaps understated the extent of its distribution, Thomson certainly overstated it. As New Zealand conditions are different from those of Britain or Europe in many ways, the behaviour of this plant would be expected to differ. For one thing *E. canadensis* would, in New Zealand, have met more vigorous competition from watercress than in Britain, for watercress* had been introduced here less than 20 years before and it immediately spread aggressively and grew to "an immense size far exceeding anything seen in Great Britain."

Thomson remarked that in shallow ponds in Dunedin *N. officinale*, unless kept severely in check, could put *E. canadensis* right out of competition in a year or two. On the other hand, he said that in narrow streams with a good flow of water *E. canadensis* tended to displace the *Nasturtium*, and that in some parts of the Avon at Christchurch and in tributary streams a species of *Nitella* could strangle them both.

*Until 1954, when Healy showed that both *N. officinale* R. Br. and *N. microphyllum Boenn.* ex Rchb. were present, watercress found in New Zealand was always called *N. officinale*. There is no specimen by which to check Armstrong's record, but *N. microphyllum* is now widespread and still a nuisance, though it certainly does not grow with such vigour as in the past.

Egeria densa Planch., Ann. Sci. Nat. Ser. III 11 : 80 1849

Elodea densa Planch., (Caspary). Monatsb. Berl. Acad. 47 1857.

Stems brittle, about 3 mm diam., leaves in whorls of 4 or more, 15–30 mm long by 4 mm wide, linear, lax; male spathe 1–3 flowered; peduncles *c.* 50 mm long, flowers 12–15 mm in diam., calyx greenish, *c.* 4 × 1½ mm, petals 3, white, 7 × 6 mm, stamens 9, golden; female flowers with 3 staminodes, 3 styles.

Only staminate plants have been found in New Zealand (Fig. 2).

GENERAL DISTRIBUTION: South America (Argentina). Naturalised in U.S.A. (Muenscher 1944), Europe (Lake Maggiore, Koch 1950), and New Zealand.

NEW ZEALAND DISTRIBUTION: Waikato Valley from Ngaruawahia down valley; Waihou (Thames) River near Hikutaia. (Fig. 4.)

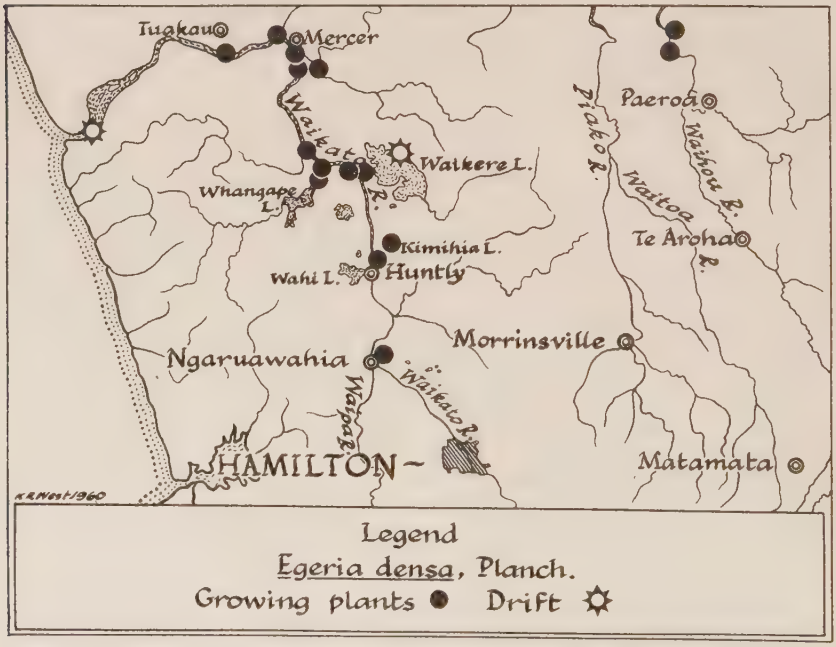

FIG. 4

SPECIMENS SEEN: Waikato River, near Port Waikato, *R. Mason & N. T. Moar 6031*; Waikato River, below Tuakau Bridge, *Mason & Moar 6052*; Waikato River, near elbow, *B. E. G. Molesworth*, 10.2.1946 (AK first New Zealand collection); Waikato River at Mercer, *Mason & Moar 7010*; Waikato River, opposite Mare Mare, *Mason & Moar 6155*; junction of Whangamarino River and Maramarua River, Waikato Co., *Mason & Moar 6972*; Waikato River, opposite Churchill, *Mason & Moar 6807*; Waikato

River, near bridge at Rangiriri, *Mason & Moar 6804*; creek from Lake Waikare, near Rangiriri station, *Mason & Moar 6914*; Lake Whangape, Raglan Co., *M. Pownall,* no date; N.E. corner of Lake Whangape, Raglan Co., *Mason & Moar 6284*; road to Lake Kimihia, near Huntly, *Mason & Moar 6427*; Lake Kimihia, east side, near Huntly, *Mason & Moar 6429*; Lake Hotoananga, 2 miles E. of Ngaruawahia, *Mason & Moar 6707*; Waihou River by wharf at Hikutaia, *Mason 7294*; Waihou River, 2½ miles S.W. of Hikutaia, *Mason 7296.*

It is not known how abundant *E. densa* was in the Waikato when it was first collected there in 1946, but today it seems to be the commonest weed in the river from Rangiriri downstream as far as fresh water aquatics go – some 35 miles or so. In 1958 large beds of the weed were found wherever the river was examined through this length; the weeds reached the surface along the river edges and formed submerged beds well into deeper waters. In Whangape Lake it was found to form broad beds a short distance off shore, apparently stretching all the way around the edge.

In the Waihou River, where it was found in November 1959, it seemed to be in scattered patches rather than great continuous beds.

Lagarosiphon major (Ridley) Moss, Trans. roy. Soc. S.Afr. 16(2):191–201 1928

L. muscoides Harvey var. *major* Ridley, J. Linn. Soc. Bot. 22:233 1886.

Stems brittle, about 3 mm in diam.; leaves alternate to subwhorled, about 16 cm long by 2 mm broad, tapering, stiff, recurved; male spathe with about 50 flowers; male flowers with 6 segments in perianth, 3 stamens, 3 staminodes; female spathe one-flowered; female flowers with perianth similar to that of male flower, staminodes 3, colourless, styles 3, stigmatic surface red. (Fig. 2c.)

No flowering plants have yet been collected in New Zealand.

GENERAL DISTRIBUTION: Africa: Transvaal and southwards. Naturalised in Europe: England, Channel Islands, Lake Maggiore (Lousley 1957, Koch 1950); and New Zealand.

NEW ZEALAND DISTRIBUTION: Middle Waikato; Rotorua district; Hutt Valley; near Blenheim. (Fig. 5.)

SPECIMENS SEEN: Mangatawhiri River, by Great South Road, *R. Mason & N. T. Moar 7002*; Waikato River, at Mercer, *Mason & Moar 7008*; Waikato River, south of outlet from Lake Waikare, *Mason & Moar, 6917*; Hamilton Lake, *Mason & Moar 6626*; Lake Rotoiti, N.I., *W. Smythe,* January 1959; Lake Rotorua, *C. B. Taylor,* May 1959; Woburn, Hutt Valley, near station, *Mason 2593*; Waiwhetu Stream, Hutt Valley, *Mason 526,* 19.1.1950 (first New Zealand collection); Waiwhetu Stream, *A. P. Druce,* June 1959; drain mouth near lower Wairau River, Marlborough, *Mason 3085*; Opawa River, Blenheim, end of Gascoigne Street, *Mason 3124*; Opawa River, near Dillon's Point School, Marlborough, *Mason 3096.*

The name "Elodea crispa" is often given to this species by those who keep aquaria, and it is sold in New Zealand under that name.

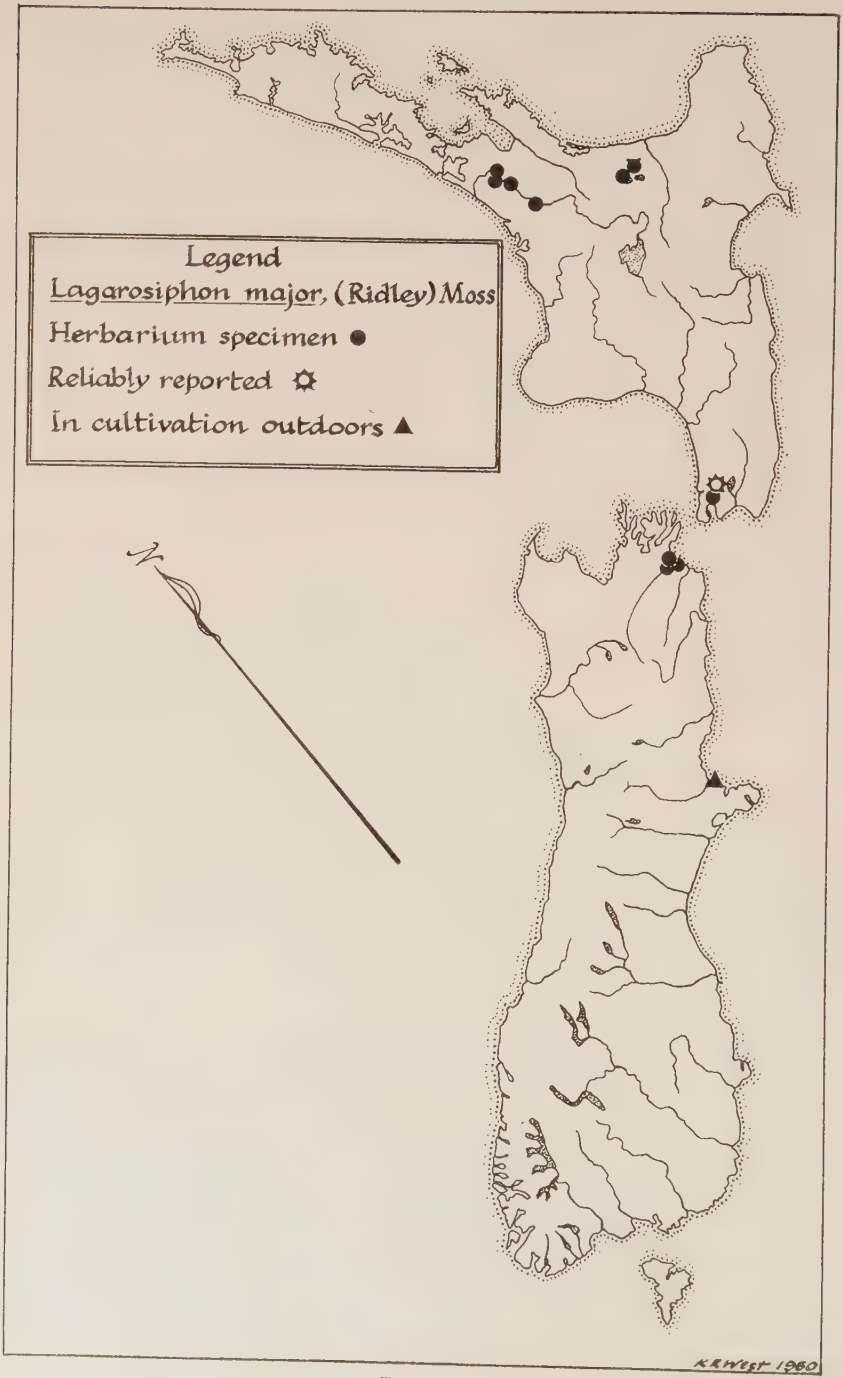
Legend
Lagarosiphon major, (Ridley) Moss
Herbarium specimen ●
Reliably reported ✡
In cultivation outdoors ▲
K.R.WEST 1980

FIG. 5

In 1950, when *L. major* was first found in New Zealand it almost covered the bed of the Waiwhetu Stream in its lower reaches above tidal influences. According to Mr A. P. Druce (in litt.) it is still abundant and is mixed with *Elodea canadensis*. He has also recently found it in a cut-off of the Hutt River behind Barton's Bush, about 8½ miles from Woburn, the nearest previously known station.

In Blenheim in the Opawa River *L. major* was in small colonies among a large growth of *E. canadensis*. The two other collections in the district were of small floating scraps.

In Lakes Rotorua and Rotoiti and in Hamilton Lake growth of this weed is sufficiently great to interfere seriously with fishing, boating and swimming. At Rotorua the position has become so alarming that a special committee including representatives of the Department of Agriculture, Lands and Survey, Internal Affairs, and the Marine Department has been formed to tackle the problem of controlling or destroying the weed. According to views held in the district, the weed has only recently begun to grow with such vigour although it has been present in the lake for a long time. It has been suggested that aerial topdressing in the district has suddenly increased the fertility of the lake water but it is far more likely that the less vigorous *E. canadensis* has been present for many years and that *L. major* is a much more vigorous newcomer attracting attention. It does not seem to have been realised that there are two species in the Rotorua lakes growing intermingled, the name "oxygen weed" covering both. In discussion with those interested in the weeds only one person offered the opinion that there are three different kinds of oxygen weed growing in the Auckland province; others who must have seen at least two species, had not distinguished them.

Establishment and Means of Distribution

Within 90 years *Elodea canadensis* has become widespread and in places abundant and it is of interest to consider whether the comparatively recent introductions, *Egeria densa* and *Lagarosiphon major*, are likely to spread so extensively.

There is a fairly widespread demand for these plants for growing in aquaria and also commercial sources of supply. The Federation of New Zealand Aquatic Societies consists of nine affiliated societies each with memberships of the order of 25 to 100, while there are many aquarists who do not belong to these societies. In the Auckland Province for instance, the only member society is that of Gisborne, although there is no reason to expect aquaria to be any less popular in that part of New Zealand. Both *E. densa* and *L. major* may be bought in the north, while in Christchurch *L. major* is cultivated commercially in a set of small ponds by one supplier, and is on sale in aquaria in Woolworths. At Hamilton Lake, *L. major* is collected by boys for sale to the shops as fish food. *E. canadensis* is widely used in aquaria and is often kept to demonstrate oxygen production by plants, and has been used for packing fish ova. If surplus material of any of these species from an aquarium is discarded into a stream or a pond it can readily become established.

In New Zealand, *E. canadensis* and *E. densa* can spread only by vegetative means, for only one sex of either has been found in the country. The same is likely to be true of *L. major,* for, though no flowering plants have yet been found here, it is probable that all plants derive ultimately from one commercial source and are of one sex.

All three are brittle plants, *L. major* perhaps the most so. A fragment of a shoot may be carried long distances by currents or floodwaters and still readily take root. Fragments may stay alive floating in water for many months; this is shown by the fact that stems 18 inches long kept in quart jars of water, in a room on a south-facing window ledge in Christchurch, were still alive after nine months, having dropped their leaves but sent out new shoots 1–3 inches long. Once established, therefore, any disturbance, including attempts to destroy the colonies by mechanical means, is likely to spread the weed to uninfested places by normal stream flow, flooding, and wildfowl.

The present distribution of *L. major* in New Zealand suggests that it may have become established several times independently. In the Waikato Valley, however, the colonies may all have originated from that in Hamilton Lake, for they are all downstream of the lake outlet, and the Mangatawhiri stand is within reach of the Waikato floodwaters.

E. densa, so far as the Waikato is concerned, may also have spread from one original infestation. It is natural to think that the plant fragments could not be washed from the river to the lakes, but as Kirk (1871) says " . . . with each rising of the river the current at first runs swiftly into lakes of lower Waikato *from* the river, instead of from the lakes *into* the river"; flood waters from the river flow also through Whangamarino Swamp. Thus every infestation down the valley from Huntly, whether in river, swamp, or lake, could have been derived from Lake Kimihia. It seems highly likely that the small patch in Hotoananga, a lake 9 miles up valley from Kimihia, the nearest station, and above flooding from the river, originated recently from material carried from Lake Whangape by black swans. It was first noticed in Hotoananga a few years ago, after there had been an unusual number of swans on the lake for some time. These swans would without reasonable doubt come from Whangape, which carries a dense population of the birds, whereas on other lakes in the district they are few and of occasional occurrence.

The three species of the Anarchariteae adventive to New Zealand come each from a different continent, North America, South America, and Africa, and already come into competition with each other to some extent, and will probably increasingly do so. At present the position appears to be that where *Elodea canadensis* comes into competition with *Egeria densa* or *Lagarospihon major* it tends to lose ground. Perhaps *E. densa* and *L. major,* whatever the underlying causes may be, are now in the phase of extraordinarily vigorous growth and rapid spread which is shown by some weeds on naturalisation, whereas *E. canadensis* has reached the stage of more normal growth which often follows. On the other hand, water temperatures may be playing a part in determining which species shall be dominant. It has been found (François 1951) that, in France, though for all three species the minimum

temperature for satisfactory growth is 10°C, the optimum temperature for *E. canadensis* is 16°, but for *L. major* and *E. densa* it is 18°C; the maximum for *E. canadensis* is 18°, for *L. major* 20°, and for *E. densa* 25°.

CHANGES IN FLORA OF THE WAIKATO RIVER

Kirk remarked (1871a) that "the paucity of fluviatile plants in the Waikato is remarkable, although some allowance must be made for the advanced season at which these observations were made". The submerged and floating-leaved species mentioned as being present were: "in shallow places in the river, *Myriophyllum variaefolium* [*M. propinquum* A. Cunn.], an undescribed *Potamogeton* allied to *P. zosteraefolius,* Schum. [*P. ochreatus* Raoul], and a species with floating as well as submerged leaves, allied to *P. natans* [*P. suboblongus* Hagstr.], and *P. heterophyllus* [*P. cheesemanii* A. Benn.], are abundant. *Nitella Hookeri* often forms large patches, and in shallow gravelly places, *Zannichellia palustris* is occasionally met with". Neither of these statements could be made today. It is still true that *N. hookeri* forms large patches; but below Karapiro Dam *Myriophyllum propinquum* and *P. cheesemanii* in 1958 were seen only once at the edge of the river – on the muddy edge where there was no shade from willows – and *Z. palustris* L., *P. ochreatus, P. sublongus,* and *Potamogeton pectinatus* L. which was recorded from the river by Cheeseman, were not found in the river at all. Though these species seem no longer to be in the river the growth of weed today must be greater and more extensive than when Kirk wrote. The growth, as indicated before, from Huntly down consists almost entirely of *Egeria densa.* Besides being abundant and clearly visible at the river margins, it can be dragged up from dense beds, though not visible from the bank, further out in the stream. The adventive species *Potamogeton crispus* L. also today occurs commonly in the river and was seen at almost every place where the river was examined. Above Huntly and as far as the waters of the Karapiro Dam the only anacharid weed seems to to be *Elodea canadensis.*

This change in the flora does not seem to be altogether due to the replacement of native aquatic plants by introduced aquatics. Today the shallower water at the margin is overhung by willows, the branches of which extend many yards over the water. None of the phanerogams mentioned by Kirk would be expected in their shade or in the deeper water. Kirk made no mention of willows on the banks of the Waikato although at the time he was recording the naturalised plants of New Zealand. The only plants on the river banks Kirk thought worth mentioning were "*Weinmannia racemosa* and other shrubs, mixed with luxuriant clumps of wharaekie (*Phormium Colensoi*)" on the high banks near Hamilton. No native trees are likely to have overhung the water to the same extent as the willows do today.

New Zealand is poor in submerged, non-marine, phanerogamic plants. There are only five indigenous species which always grow entirely submerged and of these *P. pectinatus, Z. palustris, Lepilaena bilocularis* Kirk, and *Ruppia spiralis* L. are nearly always found in New Zealand in slightly brackish or at least coastal waters, and *Z. palustris* and *L. bilocularis* are

somewhat fugitive species. This contrasts with the 28 or so species indigenous to Britain, only a few of which are confined to brackish or coastal waters. It seems therefore likely that there would be exotic species which can fill some fresh water habitats to which the few New Zealand species are poorly or not at all suited.

Egeria densa, Elodea canadensis, and *P. crispus* seem to be such species, being capable of growing in deeper and probably more swiftly flowing water than the New Zealand species, and *E. densa* also in shadier places. In various waters in the Waikato where the bottom sloped gradually the adventives did not exclude the natives in shallower water; both grew more or less intermingled, but the adventives went into deeper water also. For instance, if *P. ochreatus* and *P. crispus* were present, *P. crispus* alone was in deeper water. At the north east of Lake Whangape in shallower water a broad band of dense growth consisted principally of *E. densa* and *Myriophyllum elatinoides*, Gaud. but further out the *M. elatinoides* dropped out leaving the *E. densa*; under the willows were only *E. densa* and some *Lemna* sp.

In the Waikato all local residents spoken to seemed concerned at the greatly increased weed growth and the silting up of the river in the middle and lower Waikato in recent years. The Waikato once carried considerable traffic in the way of small vessels between the port at its mouth and Hamilton but now apparently it is possible to walk across the lower reaches if one knows the river well, a thing unheard of years ago. Some attribute the silting to the great reduction in the flow of water in April 1947, when Karapiro Dam was filling. Whatever the initial cause of any increased silting, the present growth of weed could be one factor causing greater silting than took place in the past.

CONCLUSION

E. canadensis is long established and has probably reached nearly all waters to which it is suited. *Egeria densa* and *Lagarosiphon major* are fairly newly established and their distribution is at present local but may be expected to increase, both by direct human agency and natural means. In the course of time growth of these two may become less luxuriant than it is today in the same way that the growth of *E. canadensis* became reduced after an initial short period of pronounced vigour. Though the three species were able to grow together, *E. canadensis* is suited to cooler waters than are *E. densa* and *L. major,* so that ultimately the distribution of the 3 species is unlikely to be exactly the same. Although these naturalised plants compete to some extent with indigenous plants they also fill an ecological niche unoccupied by the natives.

ACKNOWLEDGMENTS

Thanks are due to Mr W. Smythe of Auckland for specimens from Lake Rotoiti, and to Mr C. B. Taylor, Department of Agriculture, for specimens from Lake Rotorua; also to local residents who provided information.

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ADDENDUM

Since the above paper was written, a specimen of *Lagarosiphon major* collected on 18 August 1960, has been forwarded by George W. Mason, Esq. from Lake Ratapiko, Tariki, central Taranaki. This lake was not visited in the course of the 1956 collection trip.

NOTE ON PROLIFERATION IN *Rubus parvus* Buchanan

By H. E. CONNOR and E. D. PENNY,* Botany Division, Department of Scientific and Industrial Research, Christchurch

(Received for publication, 13 April 1960)

Teratological phenomena are still frequently reported and this note records a case of proliferation in *Rubus parvus*. *Rubus parvus,* indigenous to New Zealand, is the only one-foliate leaved of the native species, and has rooting stems by contrast with the other scrambling or climbing species. The flowers are said to be dioecious (Cheeseman 1925), but the plants in the Botany Division collection appear hermaphrodite as do some herbarium specimens, and are borne in short terminal or axillary panicles, or may be solitary. The fruits are very large by comparison with those of other indigenous species.

Cuttings were sent by Mr W. B. Brockie, from a plant collected at Boulder Lake, north-west Nelson, and grown in pots in a glasshouse. These cuttings and plants raised from seed from them were available for study. Flowering and fruiting were not common on samples during the two earlier seasons, but in 1959–60 it was observed that leafy proliferation at the apex of the fruit was taking place. The proliferations developed from the apex as illustrated in Fig. 1, and well developed leaves were produced on the new stem. The general appearance was that of a fruit encircling the stem, as the receptacle appeared continuous with the stem.

Three plants raised from seed from the original cuttings showed this phenomenon, and on the three plants 9 main fruits were present. From these 9 fruits six leafy shoots developed on which there were additional flowers, while three fruits gave rise to leafy shoots only. Three flowers appeared later in the season and these did not show any signs of proliferation at the time of examination. In one fruit a leafy shoot developed at the apex and bore a flower, this flower set fruit and also produced a leafy shoot. The original cuttings did not flower during this season, and Mr Brockie (*in litt.*) informs the writers that there is no proliferation on his plant of *R. parvus* from which these plants originated, though there was liberal flowering and fruiting.

Specimens of *R. parvus* in the Herbaria of the Botany Division, Canterbury Museum and Canterbury University showed no such development, and the specimens (16 in all) were from widespread localities.

In addition to this apical leafy proliferation there was a marked tendency for sepals to become leafy (sepal phyllody) (Fig. 2). Foliaceous sepals were present on 17 of 21 flowers examined, though in some, the sepals were only slightly leaf-like. The sequence from sepals to the leaf-like structures could be followed. Herbarium specimens show this phenomenon though to a slight extent only. Bond (1945) discussed sepal phyllody in *Rosa* sp. and

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FIG. 1—Proliferations from fruits of *R. parvus*. The long proliferation on the left is vegetative only; the other smaller shoot bears two flower buds.

FIG. 2—Foliaceous sepals in *R. parvus*.

shows that although this condition was in part a varietal character it was dependant principally on development after pruning which he related to hormone activity controlling vigour of growth and the balance between normal reproductive and vegetative tendencies.

The causes of these phenomena are unknown, but proliferation as an additional means of vegetative extension is an interesting phenomenon which in this case also leads to the production of more flowers and fruits. Masters (1869) describes these conditions (one of them under proliferation (*sic*)) as being frequently found in Rosaceae as well as many other families, while Arber (1950) illustrates *Geum* sp. showing both conditions on the same plant, but, so far as is known to the authors, this is the first record of proliferation in New Zealand Rosaceae.

Figures for this paper have been drawn by Mr K. R. West of the Botany Division.

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A BOUNDARY LAYER PROBLEM IN WHICH THE EXTERNAL FLOW HAS A FREE SURFACE

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Summary

The interaction of viscous and gravitational effects is examined for the case of a semi-infinite flat plate held in a horizontal plane beneath the free surface of a uniform stream. Approximate solutions are found for the boundary layer and the external flow using the assumption that the boundary layer is thin compared with the depth of the plate beneath the free surface. A solution is also given for the case of yawed flow.

Introduction

The purpose of this note is to investigate the interaction between viscous and gravitational effects in a flow which has a free surface. Problems of this type are usually very difficult, and only a few attempts at solutions have been made. Two classical solutions are well-known, namely, for the asymptotic draining of a flat plate (Nusselt 1916), (Jeffreys 1925), and for the oscillating plate with a finite depth of fluid (Stokes 1851). A boundary layer problem was examined by Ray (1948), who considered the flow from a reservoir over an infinite plane.

In the above problems the essential difficulty of combining Froude number and Reynolds number effects is avoided. This is not the case, however, in the work of Tani (1949) on the flow from a point source over a horizontal plane, and also that of Burns (1952), who has investigated the changes in the velocity of propagation of shallow water waves, due to viscous effects.

In this paper, a simple problem is considered in which a semi-infinite flat plate is held in a horizontal plane at a depth h beneath the undisturbed surface of a uniform stream. It is assumed that the appropriate Reynolds number is large enough for a boundary layer to exist on the surface of the plate, and that there is a region of reasonable extent near the leading edge in which the thickness of this boundary layer is much less than h. An approximate solution can be found using the following procedure. At each step, the fluid is first treated as being inviscid and flowing over a body of thickness equal to the current boundary layer displacement thickness. This gives an approximation to the free surface streamline and to the pressure gradient in the flow. The boundary layer is then re-calculated using this pressure gradient and a corrected external boundary condition for the velocity. In the first step, the boundary layer displacement thickness is taken to be zero. The solution is carried only as far as the second approximation as it is expected that the error involved in replacing the boundary layer by a solid body is appreciable thereafter.

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The solution as far as the second approximation shows that the interaction between the boundary layer and the external flow depends on the Froude number:

$$F = U^2/gh \quad , \tag{1}$$

where U is the velocity of the fluid upstream, relative to the plate. For $F>1$, the free surface is raised, the flow decelerates, and the pressure gradient is adverse. Hence the boundary layer displacement thickness increases and the drag on the plate decreases. For $F<1$ the effects are the opposite of these. When the leading edge of the flat plate is yawed relative to the oncoming stream, interesting secondary flows are found to occur both in the boundary layer and the external flow.

Certain features of this problem are similar to those of two other boundary layer problems. In each case, the external flow, which would otherwise be uniform and without pressure gradients, is modified by the pressure of a boundary layer. The effect of the boundary layer on the walls at the entrance to a channel or pipe, is to induce a slight acceleration (favourable pressure gradient) in the flow (Schlichting 1934), while in the simple shear flow problem (Li 1956, Glauert 1957), no pressure gradient is induced, but the boundary layer changes the external flow from $U = u_0 + \omega y$ to $U = u_0 + \omega(y-\delta)$, where δ is the boundary layer displacement thickness, and ω is the free stream vorticity.

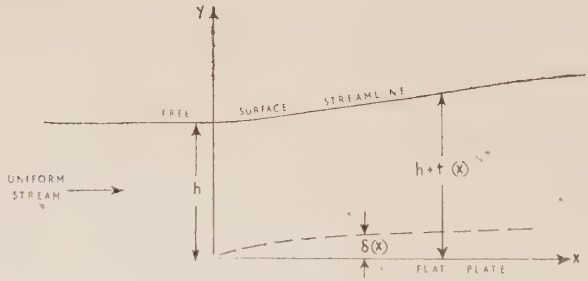

FIG. 1—Coordinate System

EQUATIONS AND BOUNDARY CONDITIONS

The coordinate system is indicated in Fig. 1 where the free surface streamline is shown as:

$$y = h + t(x) \tag{2}$$

The equations for the boundary layer (e.g., Goldstein 1938) are:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\frac{\partial^2 u}{\partial y^2} \quad , \tag{3}$$

$$0 = -\frac{1}{\rho}\frac{\partial p}{\partial y} - g \quad , \tag{4}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad . \tag{5}$$

The boundary conditions to be satisfied by u and v are:

$$u = v = 0 \text{ on } y = 0 \tag{6}$$

and at the edge of the boundary layer, u tends to the value given by the external flow solution at each stage.

Equation (4) holds throughout the flow, for if $\delta(x)$ is the current boundary layer displacement thickness, then $v = O(\delta)$ everywhere. Hence, on integration:

$$p = \pi + \rho g \{h + t(x) - y\} \quad , \tag{7}$$

where π is atmospheric pressure. Substituting this result, equation (3) becomes:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{dt}{dx} + \nu\frac{\partial^2 u}{\partial y^2} \quad . \tag{8}$$

To avoid confusion, the velocity components are written in capital letters for the external flow solution, and in small letters for the boundary layer solution. In order to carry out the procedure described in the introduction, the independent variables are written in the form:

$$X = X_1 + X_2 + \ldots , \tag{9}$$

where X represents any of $u, v, U, V, t(x)$ and $\delta(x)$. Terms with subscript (1) represent the first order approximations, those with subscript (2) the second order approximations, and so on.

The First Approximation

In the first approximation for the external flow, the boundary layer displacement thickness is taken to be zero, so that the solution is simply:

$$U_1 = U, \; V_1 = 0 \quad , \tag{10}$$

and

$$t_1(x) = 0 \quad . \tag{11}$$

Hence the boundary layer equations are:

$$u_1\frac{\partial u_1}{\partial x} + v_1\frac{\partial u_1}{\partial y} = \nu\frac{\partial^2 u_1}{\partial y^2} \quad , \tag{12}$$

$$\frac{\partial u_1}{\partial x} + \frac{\partial v_1}{\partial y} = 0 \quad , \tag{13}$$

where

$$u_1 = v_1 = 0 \text{ on } y = 0 \; ,$$

and

$$u_1 \to U \text{ at the edge of the layer.}$$

The solution of these equations, in terms of a stream function ψ_1 is, following Blasius:

$$\left.\begin{aligned} \psi_1 &= \sqrt{Uvx}\, f_1(\eta), \\ u_1 &= \frac{\partial \psi_1}{\partial y} = U f_1'(\eta), \\ v_1 &= -\frac{\partial \psi_1}{\partial x} = \frac{1}{2}\sqrt{\frac{Uv}{x}}\left\{\eta f'_1(\eta) - f_1(\eta)\right\}, \end{aligned}\right\} \tag{14}$$

where

$$\eta = \sqrt{\frac{U}{vx}}\, y \tag{15}$$

and dashes denote differentiation with respect to the independent variable. $f_1(\eta)$ is the Blasius function (e.g., Goldstein 1938), which satisfies the ordinary differential equation:

$$2f_1''' + f_1 f_1'' = 0 \ , \tag{16}$$

with boundary conditions $f_1(0) = f_1'(0) = 0$ and $f_1'(\infty) = 1$. The boundary layer displacement thickness is given by

$$\delta_1(x) = \int_0^\infty \left(1 - \frac{u_2}{U}\right) dy = \beta\sqrt{\frac{vx}{U}} \ . \tag{17}$$

Numerical integration of (16) shows that $\beta = 1.7208$. The drag coefficient at this stage is:

$$c_f(x) = \frac{v}{U^2}\left(\frac{\partial u}{\partial y}\right)_{y=o} = f_1''(0)\sqrt{\frac{v}{Ux}} \ , \tag{17a}$$

and $f_1''(0)$ is found to have the value 0.33206.

THE SECOND APPROXIMATION

It is sufficiently accurate in this approximation to use one-dimensional equations to find the external flow.* These are, the equation of continuity:

$$(U + U_2)\left\{h + t_2(x) - \delta_1(x)\right\} = Uh, \tag{18}$$

*The author is indebted to Professor M. J. Lighthill, F.R.S., for very helpful discussions on this section of the work.

and Bernoulli's equation for the free surface streamline:

$$(U + U_2)^2 + 2g\{h + t_2(x)\} = U^2 + 2gh. \tag{19}$$

Assuming that $|t_2| \ll h$ and $|\delta_1| \ll h$, then it is easily shown that for all Froude numbers except those very close to unity,

$$t_2(x) = \frac{F}{F-1}\delta_1(x) = \frac{\beta F}{F-1}\sqrt{\frac{\nu x}{U}}, \tag{20}$$

and

$$U_2 = \frac{-\beta}{F-1}\frac{\sqrt{\nu U x}}{h}. \tag{21}$$

The case for which the Froude number is nearly unity is not examined here, as a hydraulic jump can be expected to occur, modifying the flow considerably.

The boundary layer equations for this second approximation are:

$$u_1\frac{\partial u_2}{\partial x} + u_2\frac{\partial u_1}{\partial x} + v_1\frac{\partial u_2}{\partial y} + v_2\frac{\partial u_1}{\partial y} = -g\frac{dt_2}{dx} + \nu\frac{\partial^2 u_2}{\partial y^2}, \tag{22}$$

$$\frac{\partial u_2}{\partial x} + \frac{\partial v_2}{\partial y} = 0. \tag{23}$$

The solution of these equations can be written in terms of a stream function, ψ_2, such that:

$$\psi_2 = \frac{\beta}{2(F-1)}\frac{\nu x}{h}f_2(\eta), \tag{24}$$

$$u_2 = \frac{\partial \psi_2}{\partial y} = \frac{\beta}{2(F-1)}\frac{\sqrt{\nu U x}}{h}f_2'(\eta), \tag{25}$$

$$v_2 = -\frac{\partial \psi_2}{\partial x} = \frac{\beta}{2(F-1)}\frac{\nu}{h}\left\{\tfrac{1}{2}\eta f_2'(\eta) - f_2(\eta)\right\}, \tag{26}$$

where the function $f_2(\eta)$ satisfies the ordinary differential equation:

$$f_2''' + \tfrac{1}{2}f_1 f_2'' - \tfrac{1}{2}f_1' f_2' + f_1'' f_2 = 1, \tag{27}$$

with boundary conditions

$$f_2(0) = f_2'(0) = 0, f_2'(\infty) = -2. \tag{28}$$

This equation can be solved numerically by standard methods, and the function $f_2(\eta)$ and its derivatives are tabulated in an appendix to this paper. Two results of interest are:

$$f_2''(0) = -2{\cdot}7092 \ ,$$

and

$$f_2(\eta) \sim -2\eta - \gamma$$

for large values of η, where:

$$\gamma = 2{\cdot}6015 \ . \tag{29}$$

The drag coefficient c_f is given by

$$c_f(x) = 0{\cdot}33206\sqrt{\frac{\nu}{Ux}} - 2{\cdot}331\frac{\nu}{Uh(F-1)} \ . \tag{30}$$

Thus the drag is increased if $F<1$ and decreased if $F>1$. The correction to the displacement thickness is:

$$\delta_2(x) = \frac{1}{U}\int_0^\infty (U_2 - u_2)dy = \frac{\beta\gamma}{2}\frac{\nu x}{hU(F-1)} \tag{31}$$

and this represents an increase if $F>1$ and a decrease if $F<1$.

At this point the sources of error in the solution must be examined. There is an error involved in the use of equations (18) and (19) to solve for the external flow in the second approximation. An investigation shows that the use of these equations depends on $|\partial v/\partial x|$ being negligible compared with $|\partial u/\partial y|$ in the external flow. This is true, outside a small region near the leading edge, if the Reynolds number Uh/ν is very large. The error involved is then comparable with the terms in the third approximation, and thus, if the solution is to be carried further, exact equations for the external flow must be used. A more serious error, and one for which there is no compensation, is due to the method used in obtaining this solution. It is a basic assumption that the actual flow can be replaced by an irrotational flow past a solid body of thickness equal to the current boundary displacement thickness, in order to find the pressure gradient and the velocity outside the boundary layer. There will naturally be an error associated with this procedure, and intuitively this error can be expected to be of the form of a factor $(1 + O(\delta/h))$. The error in the second approximation, from this source is of order $(\delta_1/h)^2$ which is the same as the order of magnitude of the correction found in the third approximation. Thus there would appear to be no point in carrying the solution beyond this stage.

YAWED FLOW

If the flat plate is held at an angle of yaw relative to the upstream flow direction, the velocity components of the undisturbed flow are $(U, 0, W)$ where the coordinate axes remain fixed in the plate. The angle of yaw is $\mathrm{Tan}^{-1}\ W/U$ and the total flow velocity upstream is $(U^2 + W^2)^{\frac{1}{2}}$. The problem still remains two-dimensional in the sense that derivatives with respect to the z—coordinate (which is measured parallel to the leading edge of the plate) are zero, but the dependence of the w—component of velocity on x and y must be examined.

The equation satisfied by w is:

$$u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} = \nu\frac{\partial^2 w}{\partial y^2}\ , \tag{32}$$

with boundary conditions, $w=0$ on $y=0$, and $w \to W$ at the outer edge of the boundary layer. The solution for w is found to be:

$$w = W\left\{f_1'(\eta) + \frac{\beta}{2(F-1)}\frac{x}{h}\sqrt{\frac{\nu}{Ux}}\,g_2(\eta)\right\}\ , \tag{33}$$

where $g(\eta)$ satisfies the linear differential equation:

$$g_2'' + \tfrac{1}{2}f_1 g_2' - \tfrac{1}{2}f_1' g_2 = -f_1'' f_2\ , \tag{34}$$

and

$$g_2(0) = g_2(\infty) = 0\ . \tag{35}$$

The solution of this equation is tabulated in the appendix to this paper.

If the viscosity is zero, the projection of any streamline on a plane $y =$ constant, is of the form:

$$z = z_0 + Wx/U\ , \tag{36}$$

where $z = z_0$ is the point at which the streamline crosses the leading edge of the plate. With a boundary layer present, the projection of the same streamline in the external flow is:

$$z = z_0 + \frac{W}{U}\left\{x + \frac{2\beta}{3(F-1)}\sqrt{\frac{\nu}{U}}\frac{x^{3/2}}{h} + \cdots\right\}\ . \tag{37}$$

At the surface of the plate, the resultant direction of the streamline is given by:

$$\frac{dx}{dz} = \lim_{\eta \to 0}\frac{U\left\{f_1'(\eta) + \frac{\beta}{2(F-1)}\sqrt{\frac{\nu x}{U}}\frac{1}{h}f_2'(\eta) + \cdots\right\}}{W\left\{f_1'(\eta) + \frac{\beta}{2(F-1)}\sqrt{\frac{\nu x}{U}}\frac{1}{h}g_2(\eta) + \cdots\right\}}\ , \tag{38}$$

and hence the streamlines are:

$$\zeta = \zeta_0 + \frac{W}{U}\left\{ x + \frac{\beta}{3(F-1)} \frac{1}{b}\sqrt{\frac{\nu}{U}}\left(\frac{g_2'(0) - f_2''(0)}{f_1''(0)}\right) x^{3/2} + \ldots \right\} \tag{39}$$

Since $(g_2'(0) - f_2''(0)) \div 2f_1''(0)$ is approximately equal to 4, it can be seen that the streamlines are deflected about 4 times more at the surface of the plate, than they are in the external flow. For $F>1$ the streamlines are deflected towards the leading edge, and for $F<1$ they are deflected away from the leading edge.

Note that equation (27) resembles the equivalent equation found in the channel entry and shear flow problems. The left hand side is the same in each case, but the right hand side is (-1) in the former and zero in the latter. Equation (34) has the same form in each case, but since $f_2(\eta)$ is not the same the solutions for $g_2(\eta)$ are different.

APPENDIX

The numerical integration of the differential equations (27) with boundary conditions (28), and (34) with boundary conditions (35), was carried out on the Manchester University electronic computer. The results are given in tabular form below, and shown graphically in Fig. (2).

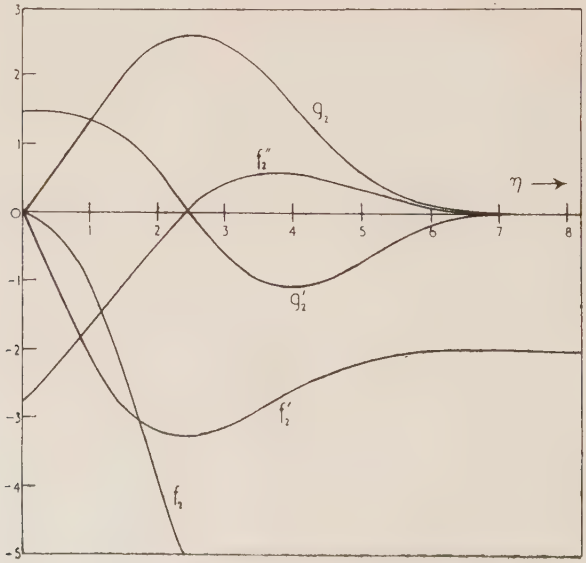

FIG. 2—The Functions $f_2(\eta)$, $f_2'(\eta)$, $f_2''(\eta)$, $g_2(\eta)$ and $g_2'(\eta)$

TABLE 1—Numerical Values of $f_2(\eta)$, $f_2'(\eta)$ and $f_2''(\eta)$

η	$f_2(\eta)$	$f_2'(\eta)$	$f_2''(\eta)$
0·0	0·0000	0·0000	−2·7092
0·2	− 0·0529	−0·5218	−2·5087
0·4	− 0·2060	−1·0032	−2·3048
0·6	− 0·4514	−1·4433	−2·0949
0·8	− 0·7805	−1·8407	−1·8771
1·0	− 1·1847	−2·1936	−1·6502
1·2	− 1·6549	−2·5002	−1·4143
1·4	− 2·1816	−2·7588	−1·1709
1·6	− 2·7551	−2·9682	−0·9230
1·8	− 3·3655	−3·1280	−0·6749
2·0	− 4·0030	−3·2385	−0·4323
2·2	− 4·6578	−3·3017	−0·2017
2·4	− 5·3207	−3·3205	0·0098
2·6	− 5·9833	−3·2995	0·1957
2·8	− 6·6382	−3·2443	0·3506
3·0	− 7·2792	−3·1616	0·4705
3·2	− 7·9015	−3·0585	0·5538
3·4	− 8·5018	−2·9425	0·6011
3·6	− 9·0781	−2·8203	0·6152
3·8	− 9·6299	−2·6983	0·6009
4·0	−10·1577	−2·5815	0·5638
4·2	−10·6631	−2·4738	0·5107
4·4	−11·1480	−2·3778	0·4478
4·6	−11·6151	−2·2949	0·3810
4·8	−12·0669	−2·2254	0·3151
5·0	−12·5061	−2·1686	0·2535
5·2	−12·9351	−2·1235	0·1987
5·4	−13·3562	−2·0886	0·1518
5·6	−13·7711	−2·0622	0·1131
5·8	−14·1816	−2·0428	0·0823
6·0	−14·5886	−2·0289	0·0585
6·2	−14·9934	−2·0191	0·0406
6·4	−15·3965	−2·0123	0·0275
6·6	−15·7984	−2·0078	0·0182
6·8	−16·1997	−2·0048	0·0118
7·0	−16·6005	−2·0029	0·0075
7·2	−17·0009	−2·0017	0·0046
7·4	−17·4012	−2·0010	0·0028
7·6	−17·8013	−2·0006	0·0017
7·8	−18·2014	−2·0003	0·0010
8·0	−18·6015	−2·0002	0·0005
8·2	−19·0015	−2·0001	0·0003
8·4	−19·4015	−2·0000	0·0002
8·6	−19·8015	−2·0000	0·0001
8·8	−20·2015	−2·0000	0·0000
9·0	−20·6015	−2·0000	0·0000

TABLE 2—Numerical Values of $g_2(\eta)$ and $g_2'(\eta)$

η	$g_2(\eta)$	$g_2{}^1(\eta)$
0·0	0·0000	1·4786
0·2	0·2957	1·4778
0·4	0·5907	1·4713
0·6	0·8835	1·4534
0·8	1·1709	1·4180
1·0	1·4491	1·3589
1·2	1·7126	1·2709
1·4	1·9552	1·1501
1·6	2·1703	0·9943
1·8	2·3507	0·8043
2·0	2·4899	0·5836
2·2	2·5825	0·3391
2·4	2·6246	0·0804
2·6	2·6145	—0·1804
2·8	2·5532	—0·4301
3·0	2·4441	—0·6557
3·2	2·2933	—0·8456
3·4	2·1089	—0·9910
3·6	1·9002	—1·0867
3·8	1·6776	—1·1316
4·0	1·4508	—1·1286
4·2	1·2290	—1·0837
4·4	1·0196	—1·0054
4·6	0·8284	—0·9036
4·8	0·6590	—0·7881
5·0	0·5134	—0·6680
5·2	0·3917	—0·5508
5·4	0·2925	—0·4423
5·6	0·2139	—0·3460
5·8	0·1532	—0·2639
6·0	0·1074	—0·1964
6·2	0·0737	—0·1426
6·4	0·0495	—0·1011
6·6	0·0326	—0·0699
6·8	0·0210	—0·0473
7·0	0·0132	—0·0312
7·2	0·0082	—0·0202
7·4	0·0049	—0·0127
7·6	0·0029	—0·0078
7·8	0·0017	—0·0047
8·0	0·0009	—0·0028
8·2	0·0005	—0·0016
8·4	0·0003	—0·0009
8·6	0·0001	—0·0005
8·8	0·0000	—0·0003
9·0	0·0000	—0·0001

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LIST OF SYMBOLS

p	pressure
ρ	density of the liquid
ν	kinematic viscosity
g	acceleration due to gravity
ψ	stream function
x, y, z	Cartesian coordinates
u, v, w U, V, W	velocity components
δ	boundary layer displacement thickness
F	Froude number
β, γ	constants
$c_f(x)$	skin friction coefficient
η	similarity variable
f, g	functions of η

Other symbols are adequately defined in the text.

A TRANSISTORISED POLAROGRAPH

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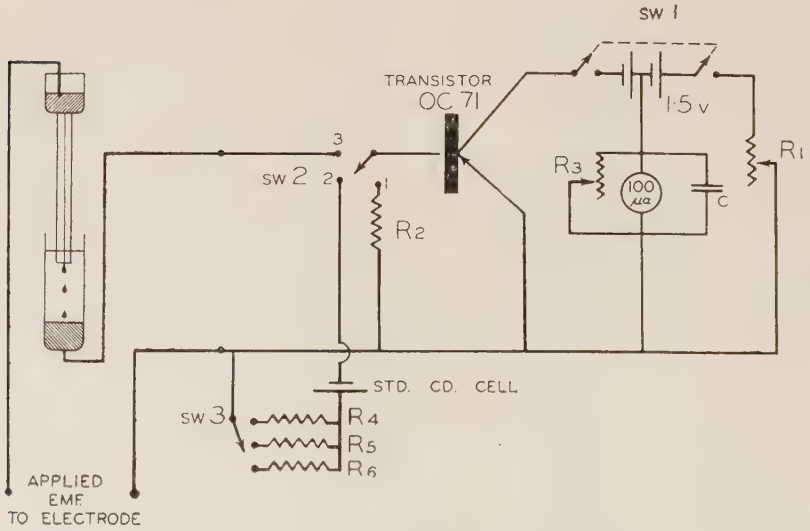
(Received for publication, 5 November 1959)

The current amplifying properties of transistors as compared with the voltage amplifying properties of electron tubes makes the former of value for electrochemical measurements where current rather than voltage is measured, such as in polarography and amperometric titrations. The use of the dropping mercury electrode needs the use of an electronic type recorder or a mirror galvanometer with a sensitivity of only several microamperes full scale or less. Neither of these instruments is portable and the latter is sensitive to vibration.

The author has applied a conventional transistor D.C. amplifier to the measurement of the diffusion current from a dropping mercury electrode, making some minor modifications in the circuit and using a standard cadmium cell as source of a small standardising current. The circuit is shown in Fig. 1. Although standard cadmium cells are normally used for supplying standard voltages, this standard voltage may be used across a resistor to provide small standardising current of several microamperes for short periods of time. According to information supplied by one



Circuit for transistor amplifier for polarograph

R_1 50,000 ohm wire wound pot
R_2 ½ meg. ohm carbon resistor
R_3 5,000 ohms wire wound pot
R_4 R_5, R_6, chosen to give suitable current values
C 500 uF electrolytic condenser

manufacturer, the standard cadmium cells produced by this firm may be used for short periods at currents up to 10 microamperes. For routine and demonstration purposes a $1\frac{1}{2}$ volt dry cell may be used if the instrument is standardised against known solutions. The high capacitance across the meter eliminates oscillations from the falling mercury drops.

This apparatus is readily portable, is not subject to vibration, and is of low cost. It has been applied to the construction of a portable oxygen meter for measuring oxygen in streams, for which lightness and ruggedness were essential. Amplifiers containing several stages of amplification with transistors arranged in bridge circuits (Shea, 1957) are also being experimented with. A high gain amplifier of this type has been applied to the titration of chlorides using polarised silver electrodes (Price and Coe, 1959).

Operation of Amplifier

Switch 1 is closed and with switch 2 in position 1, R_1 is adjusted to give zero on the meter. This allows for the high temperature coefficient of the $I_{(co)}$ value of the transistor. Now set switch 2 in position 2 and switch 3 to the required current; adjust the meter reading with R_2. Turn switch 2 to position 3 and take readings.

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THE SIZE, SHAPE, AND DENSITY OF SPORES OF *Pithomyces chartarum* (Berk. and Curt.) M. B. Ellis

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Summary

Measurements were made on air dry spores of *Pithomyces chartarum* (Berk. and Curt.) M. B. Ellis and also for spores immersed in water. The spores were found to be smaller in size than some morphologically similar pollen grains that are freely transported in air, and of comparable density when air dry. It is concluded that the spores, once detached from vegetation, should be more mobile than the pollen grains.

With the discovery that spores of the mould *Pithomyces chartarum* (Berk. and Curt.) M. B. Ellis* can cause facial eczema in sheep (Thornton and Percival, 1959) has come a need for data on the physical properties of the spores, especially those concerned with their dispersal. The size, shape, and density of the spores both in air and water are the important properties in this connection and this note reports the results of some measurements of these properties.

The shape and size of the spores of *Pithomyces chartarum* strain C were determined under the microscope; this strain was disposed by the Commonwealth Mycological Institute, Kew, England, as *Sporidesmium bakeri* Syd. (Hughes, 1953) Herb. I.M.I. No. 74473.

The spores were slightly crinkled when air dry, but in water they filled out to give a smooth elliptical outline somewhat swollen compared to the air dry condition; see Fig. 1. There was no difficulty in ascribing a major and minor diameter to the wet spores from which their volumes were calculated assuming them to be prolate spheroids. The same assumption was made in calculating the volumes of the air dry spores, but because of the crinkling of the spores in drying out, this air-dry volume will be in error by an amount it is not possible to estimate.

To obtain the density of the air dry spores, a small quantity was weighed on a micro-balance, transferred to a measuring flask and dispersed in water added up to the mark. Some difficulty experienced in wetting the spores was overcome by adding one drop of detergent and boiling the suspension for several minutes. The flask was thoroughly agitated and a sample withdrawn and placed in a Neubauer counting chamber for determining the number of spores present. Since the volume of the counting chamber is accurately known, the total number of spores weighed is estimated to be m times the number in the chamber, m being the ratio of flask volume to

*Synonymous with *Sporidesmium bakeri* Syd.

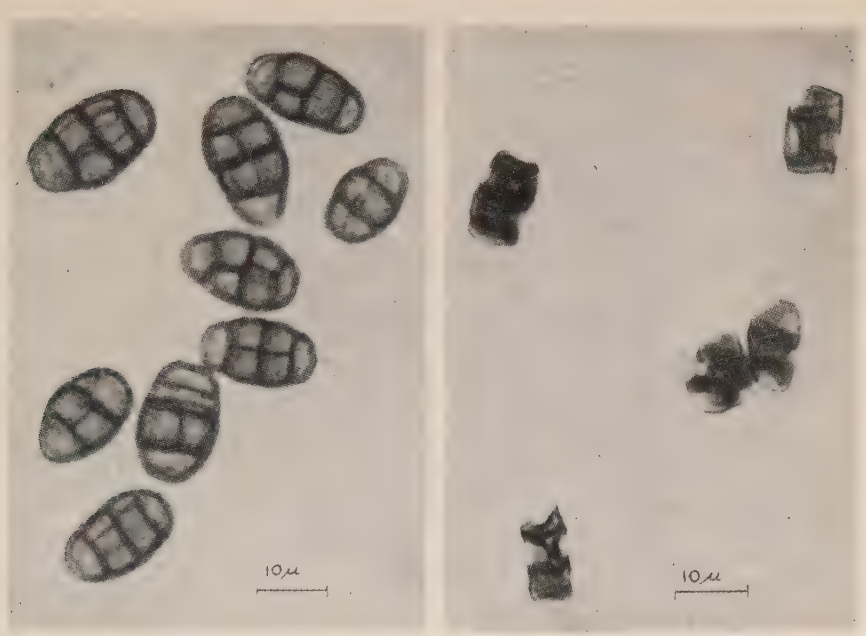

FIG. 1—Spores of *Pithomyces chartarum*.
Spores in water. Air dry spores.

counting chamber volume. Counts of fifty samples from the flask were made and the mean calculated. Thus the average air-dry weight of a single spore was found and from a knowledge of its average dimensions, the average density was obtained.

To obtain an approximate idea of the density of spores in water, a series of sucrose solutions of known density between 1·1 g/ml and 1·4 g/ml was prepared and a suspension of spores in water floated on top of the sucrose solutions. On centrifuging, the spores sank to the bottom of the tube or floated on the top depending on whether they were more or less dense than the sucrose solution. As the densities of spores and surrounding solution approached equality, longer periods of centrifuging were necessary before the direction of motion became apparent and this fact was used to interpolate between the upper and lower limits of density.

A quick but far from complete perusal of the literature failed to disclose other work done on the density of fungal spores. Pollen grains, which might be supposed to resemble spores in this connection, have been studied because of their role as atmospheric allergens, and it is interesting to compare the data found for *Pithomyces chartarum* spores with those for some common allergens. In Table 1 this is done, the data for pollen grains being those of Durham (1943). The short spicules present on ragweed and cocklebur pollen and disregarded by Durham are considered not to invalidate the comparison with *Pithomyces chartarum* spores in the present instance.

TABLE 1—Size, Shape, and Density of *Pithomyces chartarum* Spores and Some Pollen Grains

Material	Condition	Diameters (microns)	Volume 10^{-10} ml	Density g/ml
Pithomyces chartarum spores	Air dry	14.6, 9.6	7.05	0.79
Pithomyces chartarum spores	In water	17.2, 10.6	10.1	1.32
Ambrosia elatior (common ragweed) pollen	Air dry	20	41.9	0.48
Xanthium commune (cocklebur) pollen	Air dry	27	103	0.38
Salsola pestifer (Russian thistle) pollen	Air dry	23.65	69.3	0.76

From Table 1 it seems that the spores of *Pithomyces chartarum* when air dry should be as easily blown about as the pollens that are known to be freely transported by air. Even when wet, the higher density of the spores is to some extent compensated by their smaller size, so that provided they can be detached from the vegetation as single spores they should be fairly freely blown about: when wet they are only half the density of the same sized silt particles which are known to be blown considerable distances to form loess.

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STUDIES IN POLLEN MORPHOLOGY

2. THE POLLEN OF THE NEW ZEALAND AND OF TWO AUSTRALIAN SPECIES OF *Callitriche* L.

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Summary

The pollen morphology of New Zealand species of *Callitriche* and of two Australian species is described. The simple intectate exine and the lack of clearly defined apertures in several species is related to the environment of the genus. Pollen grains of *Callitriche antarctica* and *C. aucklandica* are clearly larger, and have a higher aperture number, than those of the other species described.

Introduction

In her revision of the genus *Callitriche* in New Zealand and Australia, Mason (1959) describes thirteen species. There are included notes, furnished by the present author, on the pollen morphology of the four species indigenous to New Zealand, and on *Callitriche brachycarpa, C. cyclocarpa, C. heterophylla,* and *C. stagnalis* (Table 1).

Table 1—New Zealand and Australian *Callitriche* Species Described by Mason (1959)

	New Zealand	Australia
Indigenous	*C. antarctica* *C. aucklandica* *C. muelleri* *C. petriei*	*C. brachycarpa* *C. capricorni* *C. cyclocarpa* *C. umbonata* *C. sonderi*
Adventive	*C. hamulata* *C. heterophylla* *C. stagnalis*	*C. palustris** *C. stagnalis*

*Mason (1959) states of *Callitriche palustris* that "the possibility of its being indigenous to south-eastern Australia cannot be overlooked".

In some cases reliable material could be obtained from only one specimen so that although the purpose of this paper is to expand those notes, particularly in respect of the New Zealand species, descriptions of the pollen are in some instances limited because of the lack of a range of material for examination.

METHODS

Pollen was mounted directly in glycerine jelly stained with basic fuchsin and whenever enough material was available pollen was also acetolysed (Erdtman, 1952). Measurements were based on pollen mounted in the fuchsin stained jelly and all pollen grains were examined under oil immersion.

POLLEN MORPHOLOGY

There is no detailed information available regarding the morphology of *Callitriche* pollen and the only references to New Zealand material are by Cranwell (1942) and in Mason (1959).

EXINE: Cranwell (1942) describes the exine of *Callitriche* pollen as smooth and not boldly pitted, and Faegri and Iversen (1950) include the genus twice in their key to allow for the use of objectives of low aperture which alter the clavate appearance of the exine to an apparent reticulum. Erdtman (1952) states that the exine is thin and that it may be reticulate, or finely reticulate, and Ikuse (1956) says that the exine of *Callitriche japonica* and of *C. verna* (*C. palustris*) is sub-reticulate.

Callitriche stagnalis, C. hamulata, and *C. palustris* are the only species of those found in New Zealand and Australia for which there is any description of the pollen. The pollen of *C. stagnalis* is described by Berger (1924) and by Schotsman (1954) as possessing a warty (verrucate) exine; Erdtman (1952) states that in some grains the exine is faintly retipilate, and van Campo (1951) that the exine is thick and echinulate. According to Schotsman (1954) and van Campo (1951) pollen grains of *C. hamulata* have a reduced exine from which ektexinous elements are absent. Berger (1924) describes the pollen of *Callitriche palustris* as being verrucate, Erdtman (1952) states that the exine is reticulate and the muri simplibaculate, and Schotsman (1954) discusses briefly two pollen types occurring in this species. The first type is small and globular and "generally well shaped" and is characteristic of water forms. Pollen grains of the second type are shrivelled, few in number and occur in land forms of *C. palustris*.

The exine of the pollen grains examined in this study is thin or very thin, and it is divided into a structureless inner layer, the endexine, and an outer layer, the ektexine, composed of rod-like or flattened projections (Fig. 1). These may be baculate (*Callitriche antarctica, C. brachycarpa, C. petriei,* and *C. stagnalis*), clavate (*C. aucklandica, C. muelleri*), or verrucate (*C. cyclocarpa, C. heterophylla*). Some of the baculate and clavate ektexinous elements appear to be fused at their tips, but many are not, so that the exine is intectate.

APERTURES: Apertures are mentioned briefly by Cranwell (1942), Erdtman (1952), Faegri and Iversen (1950), and by Ikuse (1956). These authors indicate that the apertures are not easily observed, but that in some species pores are present, in others there are furrows, and in others again there are aperturoid areas in the exine. In all cases the apertures are simple.

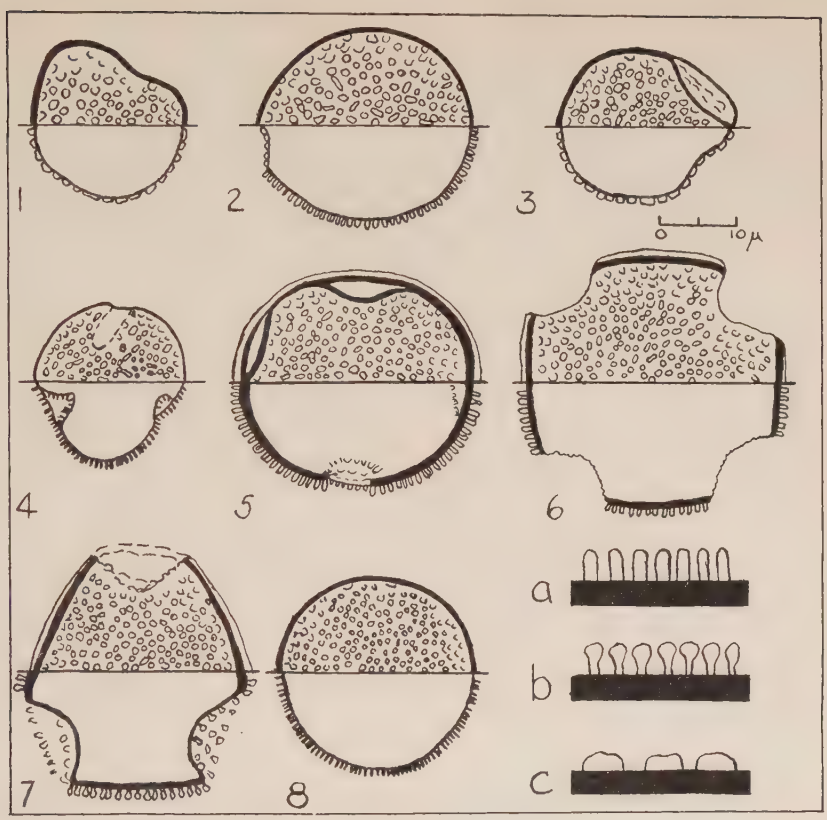

FIG. 1—Diagrammatic representation of pollen grains of some *Callitriche* species. (Upper half, surface view; lower half, optical section.)

1. *Callitriche heterophylla*; 2. *C. stagnalis*; 3. *C. cyclocarpa*; 4. *C. muelleri*; 5. *C. brachycarpa*; 6. *C. antarctica*; 7. *C. aucklandica*; 8. *C. petriei*.

a. baculate exine; b. clavate exine; c. verrucate exine.

Four of the species under discussion have aperturate pollen, and the remainder, thin aperturoid areas or "zones of weakness" in the exine. The apertures are sometimes difficult to see, but furrows occur in *C. petriei*, and pores in *C. antarctica* and *C. cyclocarpa* (Fig. 1). Aperture numbers range from three (*Callitriche cyclocarpa*) to as many as six (*C. antarctica, C. aucklandica*).

SIZE: On the basis of size the pollen may be divided into two distinct groups (Table 2).

TABLE 2—Size Range of the Pollen of Some Species of *Callitriche*

Group	Species	Size (in μ)
a	*Callitriche heterophylla*	12(16)20
	C. muelleri	13(17)20
	C. stagnalis	12(17)22
	C. petriei	17(20)22
	C. petriei var. *chathamensis*	15(19)23
	C. cyclocarpa	15(18)22
b	*C. aucklandica*	22(25)28
	C. antarctica	20(26)30
	*C. brachycarpa**	27(30)32

*Measurements based on acetolysed material and therefore cannot be compared with others.

DESCRIPTION OF POLLEN*

Callitriche muelleri Sonder

Free, isopolar, radiosymmetric; 3, sometimes 4, indistinct aperturoid areas; shape spheroidal, 4-aperturoid grains quadrangular, exine very thin, about 1μ, intectate, clavate; size 13(17)20μ.

MATERIAL: Little Barrier Island, W. M. Hamilton, grown in Botany Division gardens, Christchurch, Sl. 3704, Sl. 3705.

Callitriche brachycarpa Hegelm.

Free, isopolar, radiosymmetric; indistinct aperturoid zones; shape spheroidal; exine very thin, about 1μ, intectate, baculate; size 27(30)32μ.

Measurements were based on acetolysed material so that no comparison with the size of other species is possible.

MATERIAL: Apollo Bay, *F. Mueller,* MEL. Sl. 3708.

Callitriche antarctica Engelm.

Free, isopolar, radiosymmetric, 3–6 aperturate, in fully expanded grains almost circular pores; shape spheroidal to quadrangular; exine very thin, about 1μ, intectate, baculate; size 20(26)30μ.

MATERIAL: Campbell Island, *J. D. Hooker,* MEL. N.S.W. 33828, Sl. 3848; slopes of Mt Honey, Campbell Island, *R. L. Oliver* (Cape Expedition) Sl. 3998.

*Herbaria cited are:

CANTY, Canterbury Museum, Christchurch; CHR, Botany Division, D.S.I.R., Christchurch; MEL, National Herbarium of Victoria, Melbourne; WELT, Dominion Museum, Wellington.

Callitriche aucklandica R. Mason

Free, isopolar, radiosymmetric; 3–6 aperturate, in fully expanded grains circular, or nearly circular, pores; shape spheroidal, quadrangular, or subtriangular; exine thin, 1–2μ, intectate, clavate; size 20(25)32μ.

MATERIAL: South side Crosier Point, Auckland Island, *J. B. Hair,* Nov., 1954, CHR 89342, Sl. 3519, Sl. 4118; Auckland Island, *J. B. Hair,* Nov. 1954, CHR 89341, Sl. 3517; grown from plant collected on Auckland Island by J. B. Hair, *R. Mason,* 3288, CHR 89366, Sl. 3608.

Callitriche petriei R. Mason subsp. *petriei*

Free, isopolar, radiosymmetric; 3–4 aperturate, sometimes indistinct, furrows in fully expanded grains, slightly more than half length of pollen grain; shape spheroidal; exine very thin, about 1μ, intectate, baculate; size 17(20)22μ.

MATERIAL: Pauri Lake, S. of Wanganui, New Zealand, *R. Mason* 4134, CHR 90961, Sl. 3706.

Callitriche petriei subsp. *chathamensis* R. Mason

Close to *C. petriei* subsp. *petriei,* but definite furrows are lacking, there being aperturoid zones, and the size range, although based on inadequate material varies slightly, 15(19)23μ.

MATERIAL: L. Huro, Chatham Island, *B. G. Hamlin* 659, WELT, Sl. 3850; Tupuangi Lagoon, Pitt Island, *B. G. Hamlin* 692, WELT, Sl. 3849; Waitangi, Chatham Island, *L. Cockayne and F. A. D. Cox* 1480, WELT, Sl. 3606.

Callitriche heterophylla Pursh emend. Darby var. *heterophylla*

Free, isopolar, radiosymmetric; apertures vague, some grains appear non-aperturate, others, 2–3 ill-defined aperturoid areas; shape spheroidal; exine very thin, about 1μ, intectate, verrucate; size 12(16)20μ.

MATERIAL: Waikato R., New Zealand, *T. F. Cheeseman,* April 1900, CANTY 851/4 Sl. 3604.

Callitriche stagnalis Scop.

Free, isopolar, radiosymmetric; non-aperturate, or with small, irregular aperturoid zones; shape spheroidal, sometimes elongate elliptic; exine very thin, about 1μ, intectate, baculate; size 12(17)22μ.

MATERIAL: Otekairangi, *R. Mason and N. T. Moar* 394, CHR 69686, Sl. 2681; Otekairangi, *R. Mason and N. T. Moar* 395, CHR 69687, Sl. 2676; Maitahi, Kaihu R, *R. Mason and N. T. Moar* 28, CHR 65828, Sl. 2678; E. of Opononi, *R. Mason and N. T. Moar* 136, CHR 65866, Sl. 2679; Bonnetts' Road, Kaitaia, *R. Mason and N. T. Moar* 257, CHR 69512, Sl. 2680; Ohariu Valley, *R. Mason,* CHR 64068, Sl. 3607; Pohangina Valley, *N. T. Moar* 2545, CHR 92339, Sl. 3713.

Callitriche cyclocarpa Hegelm.

Free, isopolar, radiosymmetric; 3-aperturate, large circular, sometimes indistinct; exine very thin; about 1μ, intectate, verrucate; size 15(18)22μ.

MATERIAL: Swan Hill, Murray R., *J. G. Luehmann,* 1890, MEL. Sl. 3707.

DISCUSSION

The environment of a plant and its mode of pollination is reflected in the structure of the exine of its pollen. Wodehouse (1935) and van Campo (1951) refer to the reduction of exine in the pollen of aquatic plants, particularly in those plants in which pollination is effected under water. In this connection Wodehouse (1935) comments in a discussion on aquatic monocotyledonous plants that it is more than a coincidence that in plants that are pollinated under water the pollen grains are without exine, whereas the pollen of plants with emersed flowers possess an exine in a reduced form.

The environment of *Callitriche* species ranges from an aquatic, to a terrestrial one (Mason, 1959). The terrestrial species (Mason pers. comm.) do not occur in dry or desiccating situations. The structure of the flower suggests that the species discussed in this paper are probably anemophilous (except *C. hamulata*) and the nature of the exine and the apertures of the pollen supports this view. Clapham et al. (1952) record that *Callitriche stagnalis* is usually anemophilous, and Schotsman (1954) states that in water forms of this species the pollen is often shed on to the water where it floats until it comes into contact with the stigmas of a female flower.

The pollen of the species described do not fall into any clearly defined groups on the basis of their morphology and the only possible basis for separation is that of size (Table 2). The marked difference in size between *Callitriche antarctica* and *C. aucklandica* and the remaining species suggests that a polyploid series may be found within the group, as does the increase in aperture number. That polyploidy does occur within the genus is suggested by the variation in diploid numbers and the record of secondary haploid numbers reported by Darlington and Wylie (1955).

Callitriche pollen is rarely found in New Zealand peats, lignites and other deposits, but *C. antarctica* has been recorded in peat from Antipodes Island and from Campbell Island, and *C. petriei* has been provisionally identified from post-glacial peats in the north west Ruahine Ranges, North Island, New Zealand.

ACKNOWLEDGMENTS

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THE RECOVERY OF SALTS FROM GEOTHERMAL WATER BY ELECTRODIALYSIS

1—CELL DESIGN AND PLANT LAYOUT

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Summary

This paper describes a three-compartment electrodialysis cell, designed for the concentration of salts from geothermal water under continuous flow conditions. Emphasis is placed on inter-compartment separator design, and details of the associated plant layout are given.

INTRODUCTION

Wairakei geothermal water contains several minerals of sufficient economic interest to justify a detailed investigation into their possible recovery (Wilson, 1959). Chloride is the main anion (2,100 p.p.m. in high-pressure bore water) and the more important cations are sodium (1,240 p.p.m.), potassium (200 p.p.m.) and lithium (14 p.p.m.) with lesser amounts of rubidium and caesium. It has been suggested by Dr A. M. Kennedy, in a 1957 Dominion Laboratory Report (C.E. 180) that it might be economically possible to concentrate and recover these minerals by electrodialysis, a technique more commonly used for producing fresh water from brackish (Kirk and Othmer, 1950; Spiegler, 1956). The main aim of the present investigation was to see whether such concentration would be technically feasible, so that more detailed consideration could be given to the economics of the process.

Laboratory-scale electrodialysis equipment has not been available commercially and information on full-scale de-salting units is of limited application to a particular problem such as the one under consideration. If full advantage is to be taken of membrane selectivity, equipment must be carefully designed, with special attention to hydrodynamic considerations. A considerable amount of developmental work had, therefore, to be carried out before quantitative de-salting tests could be performed. The apparatus finally developed is described in this paper.

EQUIPMENT DESIGN

General Requirements

The value of electrodialysis as a technique for de-salting water is dependent on the cation and anion selective membranes retaining their selectivity under practical operating conditions. Polarisation due to concentration changes at the membrane surface can lead to a significant drop in membrane

selectivity and, for this reason, practical installations must be run under comparatively depolarised conditions (Cooke and Mandersloot, 1959). Under given conditions of current density and solution concentration the extent to which polarisation occurs will depend on hydrodynamic flow conditions in the cell and, consequently, on the design of intercompartment separators or baffles. In planning this work, therefore, separator design posed a major problem.

Other factors which influenced the design of the apparatus were the need to operate over wide ranges of flow-rate, current density, and temperature, and the desirability of being able readily to dismantle the equipment for inspection or cleaning. Provision was needed for altering the number of compartments in the cell, and to allow for series or parallel flow operation.

Basic Assembly

A three-compartment cell arrangement was used initially, as it was simpler to make and study and, at this stage, the power economy of multi-compartment operation was only of secondary interest. Components of the cell are shown in Fig. 1.

The membranes (1, 7) are, respectively, Permaplex C10 (cation) and A10 (anion), manufactured by the Permutit Co. Ltd. and described elsewhere (Kressman and Tye, 1956). Six inch square sheets were used with a free membrane area of 19·6 in^2.

The end-plates (2, 6) which carry the electrodes were formed by cementing a 4 in. diameter, $\frac{1}{2}$ in. thick graphite disc into a 6 in. square of perspex, $1\frac{1}{2}$ in. thick, and machining off to a flat surface. These end-plates carry suitable connections for the various influent and effluent streams and $\frac{1}{8}$ in. brass rods are screwed radially through the perspex into the graphite electrodes to provide external connection to the power supply.

In assembling the cell, membranes are clamped between 6 in. square polyvinyl chloride (P.V.C.) spacers which act as frames for the various compartments as well as distributing the flow streams. In most of the experimental work, $\frac{1}{8}$ in. thick spacers were used for all compartments. Figure 1 shows these spacers together with the separators used to hold apart and support the membranes (3, 4, and 5). The design of these separators is referred to in more detail below.

The cell assembly is sketched in exploded form in Fig. 2. The components are held together in a screw-type press, Fig 3 (6), under sufficient pressure to maintain a tight seal between compartments and prevent internal leakage between separate flow paths.

Plant Layout

Figure 3 shows the general layout of the plant and its associated power supply, solution feed system, and electrical and flow measuring instruments. The electrode and dialysate solutions are prepared in separate P.V.C. tanks (1) equipped with stirrers, and are pumped from here to overhead constant-

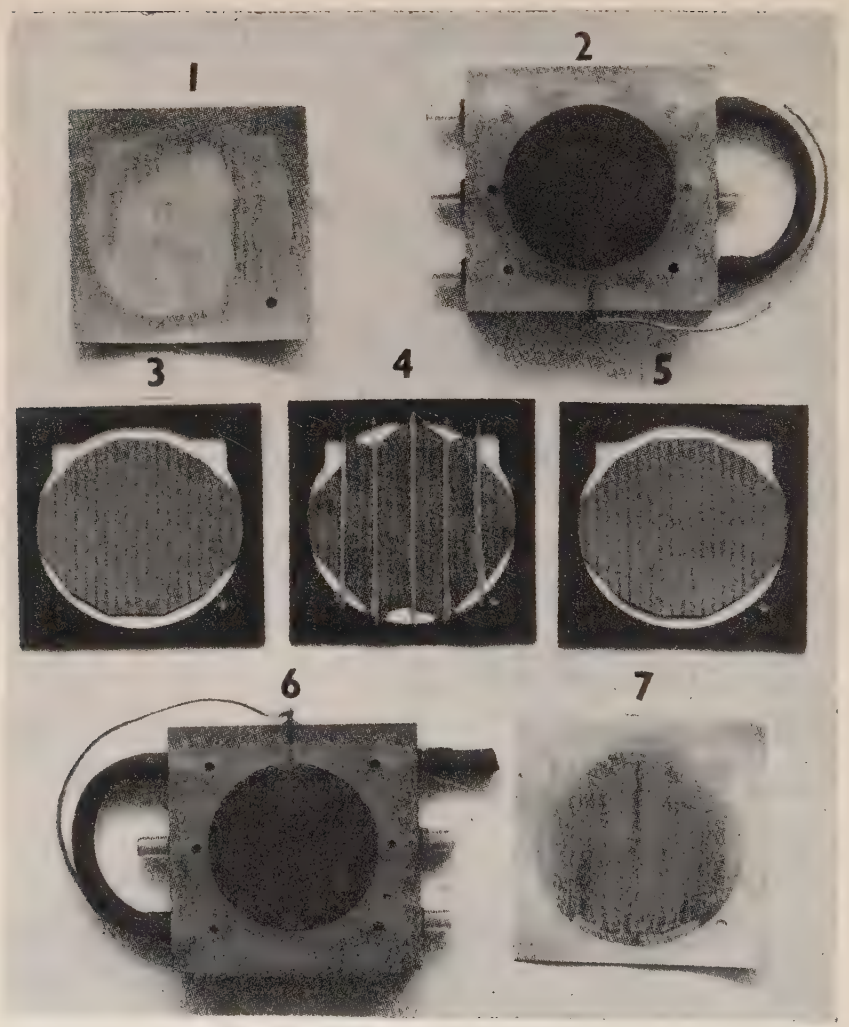

FIG. 1—Components of the experimental cell.

level Mariotte bottles (2) at the start of a run. Solution feed-rates are determined during the run from the rate at which air flows into these bottles to replace liquid flowing out, using soap-film meters (11) for this measurement. This method of flow-measurement allows liquid flow-rates to be determined with an error of less than 1%. The solutions, on leaving the Mariotte bottles, are passed through coils immersed in a thermostatically controlled water-bath (3) which allows cell inlet temperatures to be held constant to within ± 1°C in the range 20°–60°C. Capillary flow-meters (4) with dibromoethane as manometer fluid are used to simplify the setting

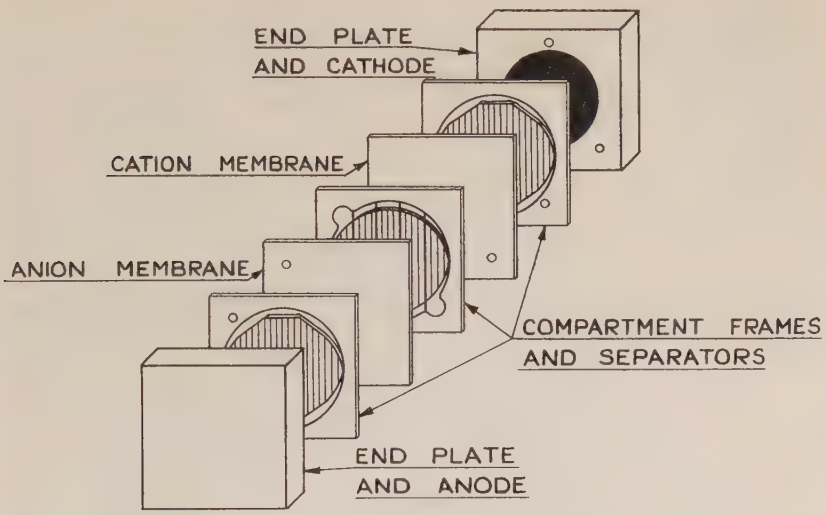

FIG. 2—A diagrammatic sketch of the cell assembly in exploded form.

and adjustment of flow-rates. Electrode flow-rates of up to 300 ml/min., and a dialysate rate of up to 120 ml/min. can be handled by these meters and a bypass across each capillary allows higher rates to be used when necessary. Flow-rates are controlled by adjusting screw clips on the inlet tubing to the cell (5) and sample cocks are provided on influent and effluent flow-lines. Temperature differentials across the cell can be measured by inserting thermocouples into the flow-lines.

Power Supply

The power supply and control board are shown in Fig. 3 (8) and a diagrammatic sketch of the electrical circuit is given in Fig. 4. D.C. power is supplied to the cell from 12 V, 11-plate accumulators in series (see Fig. 3 (7)) as required. A 0–55 ohm rheostat (R1) (Fig. 4) is used for approximate current adjustment and a 0–10 ohm rheostat shunted with a 3 ohm resistance (R2) provides precise control. Portable, multi-range, moving coil test-meters (Avometer) (Fig. 3 (9)) are used to measure voltage drop across the cell and the current passing in a given run. These were checked against standard meters and found to have an error not greater than 1% of the full-scale value over the effective range.

An auxiliary 6V supply and rheostat (R3), (Fig. 4) were used in conjunction with a double-pole double-throw switch (DS) to measure the back e.m.f. exerted by the cell under varying conditions of solution concentration and current density. This measurement was needed to allow the cell resistance to be computed. When the normal power supply is cut off by the main switch (S) after a run, the voltmeter (V) registers the back e.m.f. This decays rapidly, making it difficult to measure the initial value precisely. By

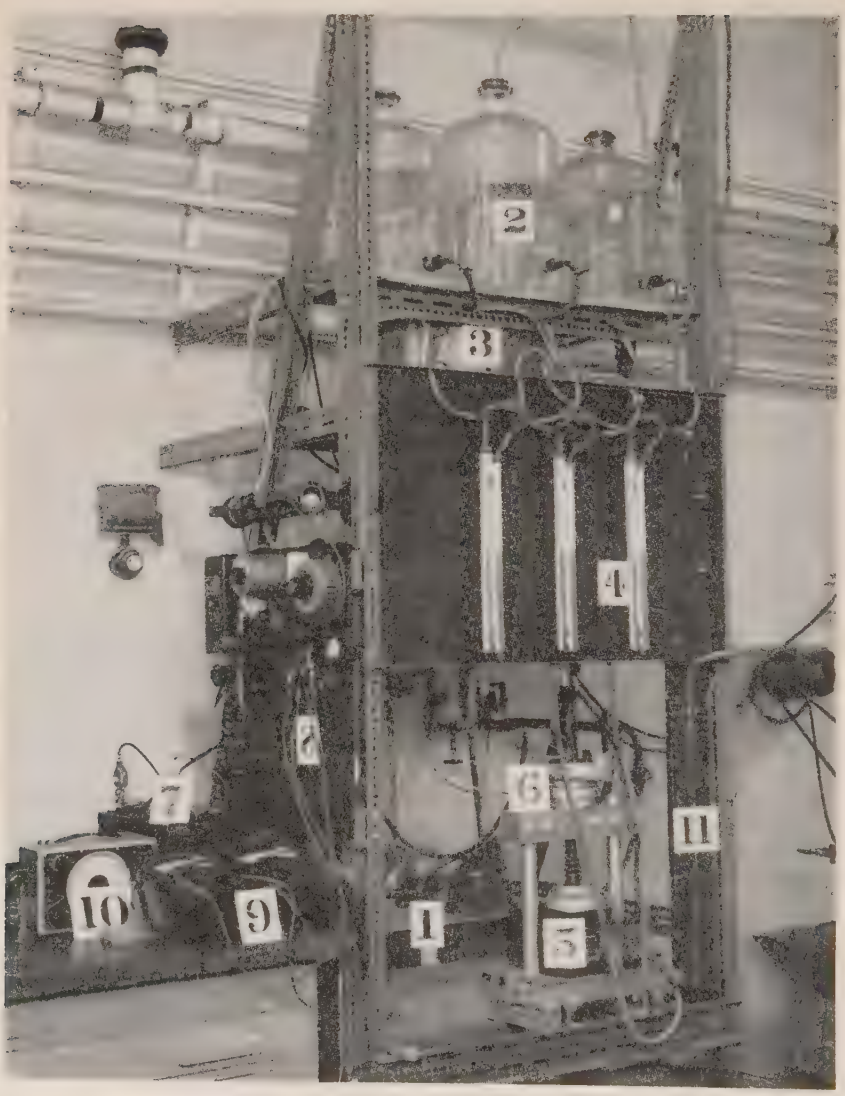

FIG. 3—Arrangement of apparatus.

operating the switch (DS) during a run, however, the opposing voltage can be adjusted by trial and error until no deflection is observed on the meter (A) as the switch is thrown from the main to the auxiliary power supply. Under these conditions, a direct null-point reading of the back voltage is obtained.

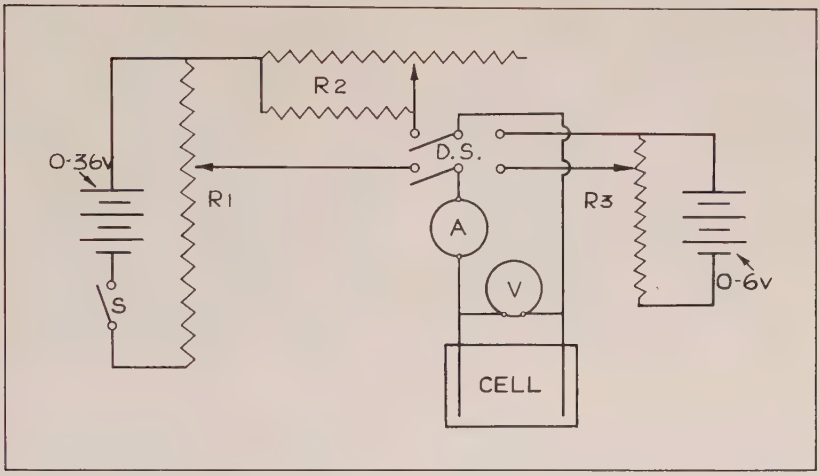

FIG. 4—Electrical layout.

SEPARATOR DESIGN

Aluminium Powder Injection Tests

Intercompartment separators are needed to keep the membranes uniformly spaced and to provide a positive flow-path for liquid passing through the compartment with provision for adequate remixing at intervals. At low flow-rates, or with insufficient agitation, a significant degree of concentration polarisation may occur in diffusion layers adjacent to the membranes. Besides lowering the current efficiency, by allowing unwanted ions to pass through the membranes, polarisation can increase the cell resistance and lead to pH changes at the membrane surfaces. This may result in undesirable sludge formation, especially in a complex medium like Wairakei bore water.

In an attempt to avoid these conditions in the cell, separators were fabricated from various materials, including fibre-class cloth, stainless steel mesh, round P.V.C. rods and sheets of "Porvic", a porous, ribbed form of P.V.C. used for battery separators. Preliminary evaluation was carried out by clamping the separators in a compartment frame between plates of 1 in. perspex, provided with suitable flow connections. By injecting fluorescein or an aqueous suspension of aluminium particles into the influent, flow patterns could be studied at various flow-rates.

Fig. 5 shows a sequence of patterns obtained with a six-pass separator constructed from $\frac{1}{8}$ in. diameter P.V.C. rods. The flow-rate in this particular test was 125 ml/min. corresponding to an average Reynolds number of about 230. A marked degree of short-circuiting is evidenced by the dead spots occurring about the junctions between passes. Polarisation would be severe in these areas, pointing to a need for more effective baffling.

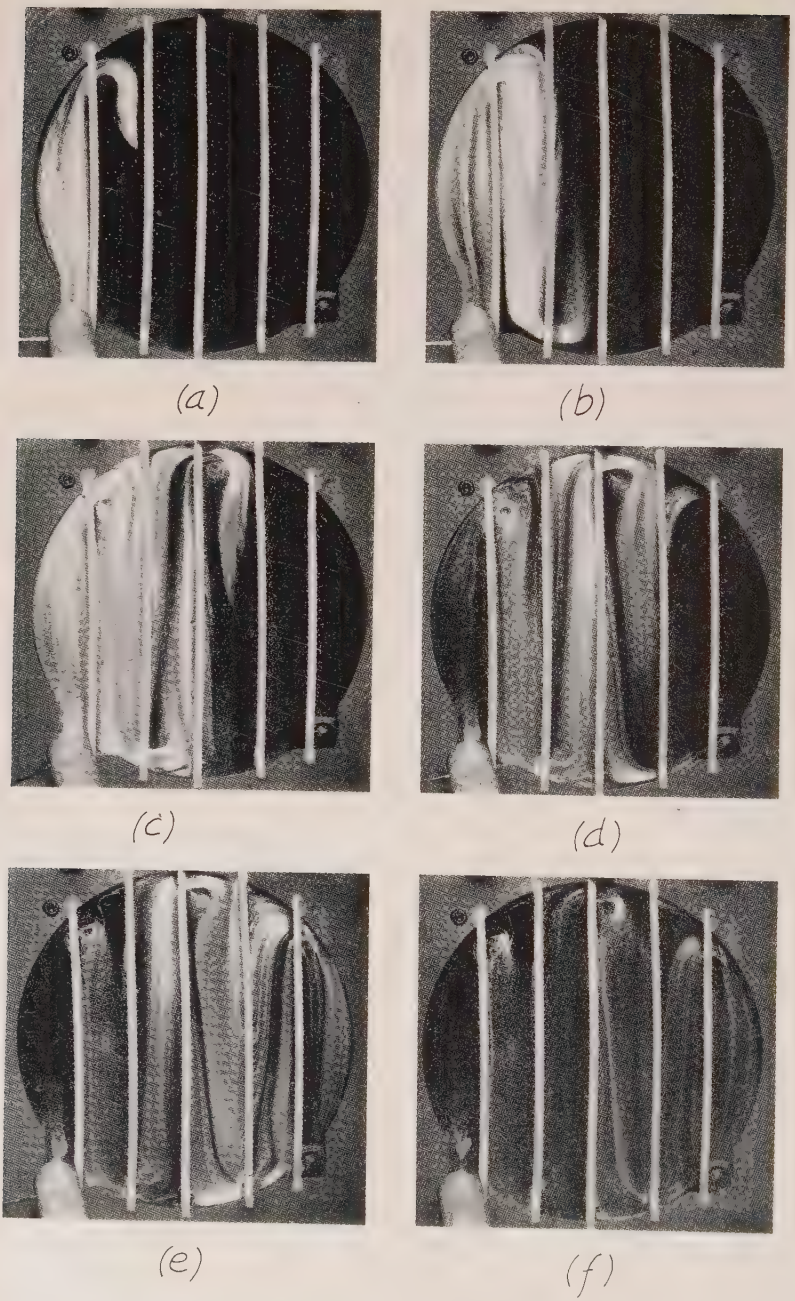

FIG. 5—Sequence of flow patterns through a compartment separator with aluminium powder as tracer.

Operating Resistance Tests

Injection tests of the kind described above were used as a basis for selecting electrode and dialysate compartment separators. To support these tests the various separators were fitted in turn into a cell assembly and cell resistance was computed as a function of solution flow-rate under actual operating conditions. Unsatisfactory flow conditions were expected to result in a significant dependence of resistance on flow-rate.

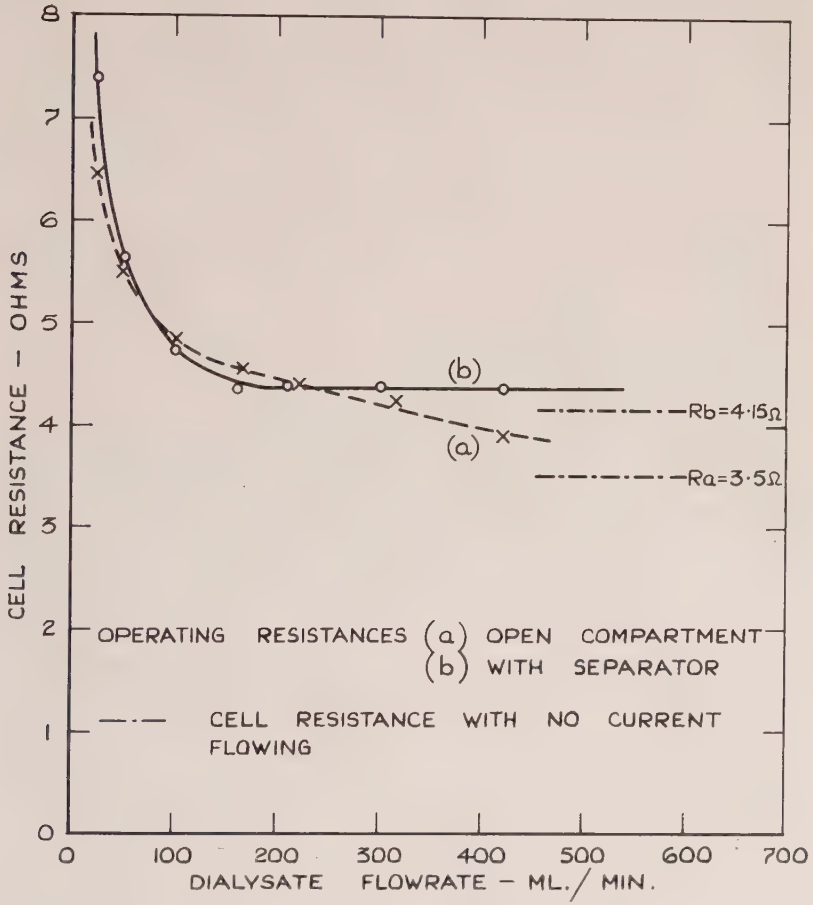

FIG. 6—The relation between cell resistance and dialysate flow-rate.

Typical results are shown in Fig. 6. A three-compartment cell was assembled with "Porvic" sheet separators in the electrode compartments (see below). Sodium chloride solutions (0·1 N) were circulated through each of the electrode compartments at a fixed rate of 250 ml/min. and at

varying rates through the central dialysate compartment. In a given measurement, once flow-rates were steady, a voltage was applied to the cell and adjusted to give a steady current of 1·0 amp. The voltage drop across the cell (V) was then measured and the internal resistance of the cell calculated from the equation

$$R = \frac{V - V_b}{I} = (V - V_b) \text{ since } I = 1{\cdot}0$$

Values of R are plotted against dialysate rate in Fig. 6

(a) without a separator in the dialysate compartment; i.e., unrestricted dialysate flow;

(b) with a separator fabricated from $\frac{1}{8}$ in. P.V.C. rods dividing the compartment into six passes, with strips of $\frac{1}{16}$ in. "Porvic" sheeting placed back to back in each pass, as shown in Fig. 1.

In the former case a greater head of liquid was maintained in the centre compartment to hold the membranes against the outer separators.

In each case the internal resistance of the cell was also determined directly with the aid of a Philips conductivity measuring bridge (Fig. 3 (10)) (GM 4249/01) and the appropriate values for the two assemblies are shown as base lines to the corresponding curves in Fig. 6.

Without the separator, the cell resistance is still dependent on flow-rate at the highest rate observed here. The drop in resistance between 200 and 400 ml/min. is 0·4 ohms, all of which must be due to a drop in solution resistance in the centre compartment, since conditions in the outer compartments remain constant. As the centre compartment resistance, measured under non-polarising conditions, was only 0·3 ohms, a change of this order suggests that severe concentration changes are occurring at the membranes under the conditions obtained with unrestricted flow, even at considerable flow-rates. With the separator in position, however, cell resistance is independent of flow-rate beyond 150 ml/min. and close to the value measured directly. It should be noted that changes in resistance due to the different amounts of de-salting that occur at a given current with different flow-rates were insignificant beyond a dialysate rate of 50 ml/min.

The separator described above was selected as the most suitable on the basis of these as well as the visual flow tests. Rather less elaborate separators were chosen for the electrode compartments as it was intended in subsequent experimental work to maintain fairly high circulation rates here. Of main concern was the need to restrict movement of electrode products toward the membranes. The supports chosen are shown at 3 and 5 in Fig. 1 and consist simply of two sheets of ribbed "Porvic" placed back to back in the compartment and cut away at the inlet and outlet to provide a uniform flow velocity across the electrode and membrane faces. Visual flow tests showed that gas removal from the electrode compartments was very effective with these separators whereas, with a more open compartment, there was a tendency for stagnant pockets of gas to remain behind.

Testing for Solution Leakage

To test for leakage of solution between compartments, 0·1 N NaCl was circulated in the centre compartment at rates up to 450 ml. per minute and distilled water in the outside electrode compartments at rates up to 600 ml per minute. An average differential head, ranging from 12 to 36 inches of water, was maintained between centre and outside compartments. Samples from the electrode streams were analysed for chloride after circulating for one hour. The total leakage rate to the electrode compartments varied from 2 ml per hour under a head of 12 in. to 5 ml at 36 in. This leakage can be attributed to the slight permeability of the membranes to water under a hydrostatic head (the Permutit Coy. Ltd.). Its effect on concentration would be insignificant in comparison with the effects of normal transport processes in the cell.

ACKNOWLEDGMENTS

Thanks are expressed to Exide Batteries of New Zealand, Ltd., who supplied the "Porvic" battery separators.

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CONTRIBUTIONS TO A CHROMOSOME ATLAS OF THE NEW ZEALAND FLORA—4

MISCELLANEOUS FAMILIES

By J. B. HAIR and E. J. BEUZENBERG, Botany Division, Department of Scientific and Industrial Research, Christchurch

(Received for publication, 7 June 1960)

Summary

Documented chromosome numbers are provided for 30 species and a reputed hybrid, in 21 genera (from 14 families) of New Zealand plants.

ACKNOWLEDGMENTS

Miss L. B. Moore, M.B.E., Senior Botanist, Botany Division, Department of Scientific and Industrial Research, kindly checked the nomenclature used in this study. For living material supplied, the authors are indebted to their colleagues, particularly to Mr W. B. Brockie, Otari Gardens, Wellington, for the donation of plants of 15 species; to Mr R. Hair and Mr V. C. Davies of New Plymouth; and to Mr H. E. Gilpin, Director of Parks and Reserves, Christchurch.

TABLE 1—Documented Chromosome Numbers of New Zealand Plants: Miscellaneous Families

Species	n	2n	Source	Herb No.
CHENOPODIACEAE				
Salicornia australis Sol. ex Benth.	9	18	South Brighton, Christchurch	100293
			South Brighton, Christchurch	200305
CORYNOCARPACEAE				
Corynocarpus laevigatus Forst.	22	—	Otari, Wellington	200277
CUNONIACEAE				
Ackama rosaefolia A. Cunn.	16	—	Cultivated plant, New Plymouth	100856
			Otari Gardens, Wellington	200278
Weinmannia sylvicola Sol. ex A. Cunn.	15	—	Otari Gardens, Wellington	200299
W. racemosa Linn. f.	15	—	Otari, Wellington	200280
			Botanic Gardens, Christchurch	200304
ESCALLONIACEAE				
Carpodetus serratus Forst.	—	30	Cultivated plant, Christchurch	100107
GERANIACEAE				
Pelargonium inodorum Willd.	11	—	Levin	102005
GESNERIACEAE				
Rhabdothamnus solandri A. Cunn.	37	—	Tataraimaka, Taranaki	101610

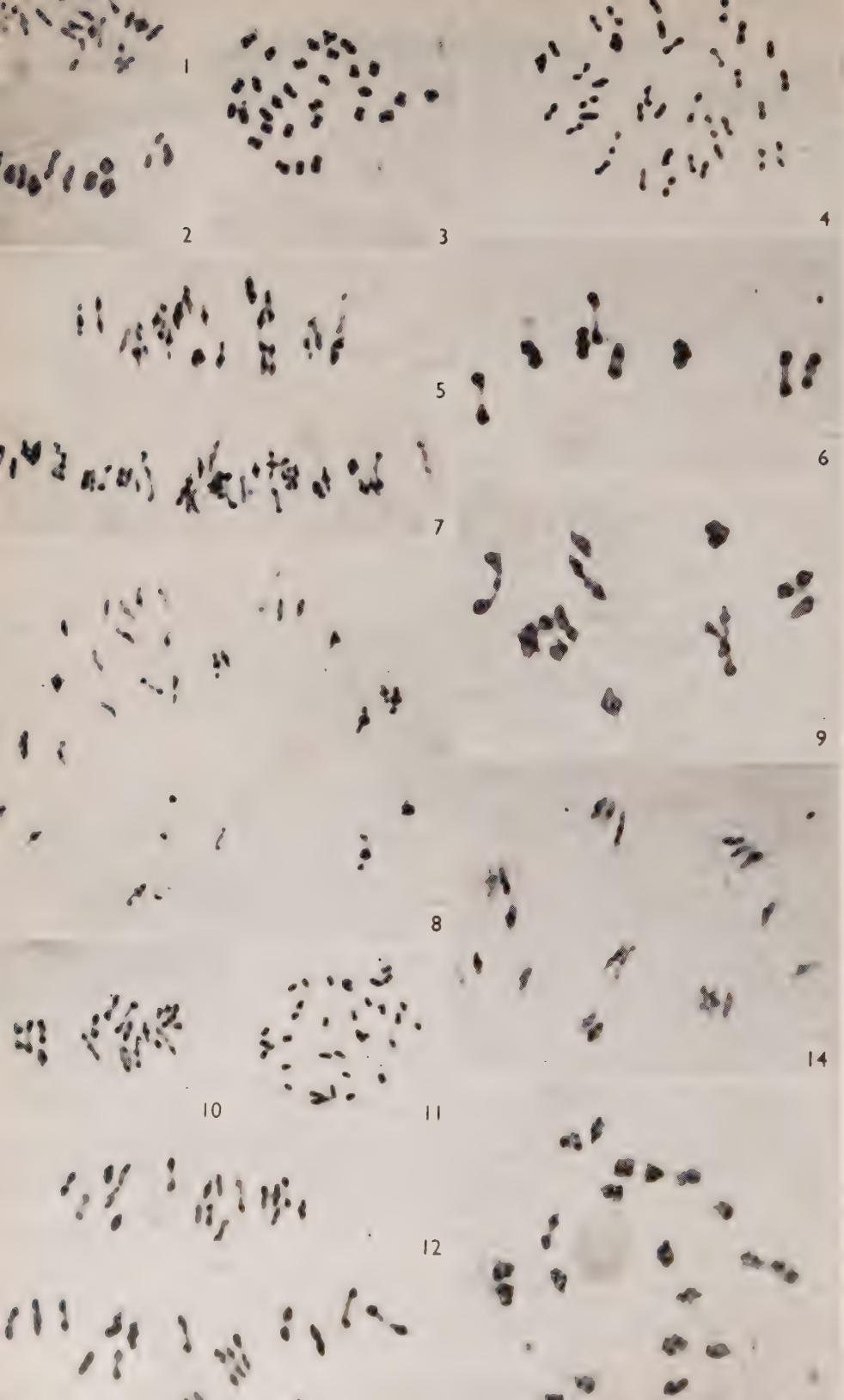
TABLE 1—*continued*

Species	n	2n	Source	Herb No.
GOODENIACEAE				
Selliera radicans Cav.	8	16	South Brighton, Christchurch	100297
LABIATAE				
Mentha cunninghamii Benth.	36	—	Kowhai River, Canterbury	100996
Scutellaria novae-zelandiae Hook. f.	30	—	Pelorus Valley, Marlborough*	101326
LAURACEAE				
Beilschmiedia tarairi Benth. et Hook. f. ex Kirk	12	24	Cultivated plant, Auckland	200306
			Coromandel	101963
B. tawa Benth. et Hook f. ex Kirk	12	—	Otari, Wellington*	200307
POLYGONACEAE				
Rumex flexuosus Sol. ex Hook. f.	20	—	Lake Lyndon	100940
			Mt Herbert, Banks Peninsula	100272
R. neglectus T. Kirk	20	40	French Islet, Auckland Islands	101169
RUTACEAE				
Phebalium nudum Hook.	16	32	Cultivated plant, Auckland	200308
Melicope ternata Forst.	—	36	Ngauranga Gorge, Wellington*	101966
var. *mantelli* (Buchan.) Kirk†	18	—	Otari Gardens, Wellington	200310
M. simplex A. Cunn.	18	—	Riccarton Bush, Christchurch	200311

SCROPHULARIACEAE				
Jovellana sinclairii (Hook. f.) Kranzl.	18	36	Whakapunake, East Cape District	101998
J. repens (Hook. f.) Kranzl.	18	36	Heaphy Track, above Aorere River, Nelson*	101245
			Tataraimaka, Taranaki	101624
Mazus pumilio R. Br.	19	38	Bay of Plenty	100151
M. radicans (Hook. f.) Cheesem.	52		Stewart Island	100147
Limosella lineata Glück	30	—	Lake Lyndon	100948
UMBELLIFERAE				
Centella uniflora (Col.) Nannfeldt	38	—	Lower Pouakai Range, Tataraimaka, Taranaki	100562
			Wallaceville	101215
Coxella dieffenbachii (F. muell.) Cheesem. et Hemsl.	11	22	Chatham Islands*	101240
Angelica montana (Forst.) Cockayne	11	22	Porters Pass, Canterbury	100051
			Lake Harris Saddle, Fiordland	200260
A. decipiens Hook. f.	11	22	N.W. Nelson	101832
A. trifoliolata (Hook. f.) Cockayne	11	22	Kowhai River, Canterbury	100997
A. geniculata (Forst. f.) Hook. f.	11	22	Near Lyttelton, Banks Peninsula	100810
A. rosaefolia Hook.	11	22	Otari Gardens, Wellington	100209
			Rangitikei Valley, Kaimanawa Mts.*	100121
URTICACEAE				
Australina pusilla Gaud.	12	24	Otari, Wellington	101330

*Grown on at Otari Gardens, Wellington.

†Reputed hybrid between *Melicope ternata* and *M. simplex*.



Unless otherwise stated, all figures are of first metaphase of meiosis. ×1500.

FIG. 1—*Weinmannia racemosa* (n = 15), 15^{II}.

FIG. 2—*Pelargonium inodorum* (n = 11), 11^{II}.

FIG. 3—*Carpodetus serratus* (2n = 30), mitotic metaphase.

FIG. 4—*Rhabdothamnus solandri* (n = 37), 37^{II}.

FIG. 5—*Corynocarpus laevigatus* (n = 22), 22^{II}.

FIG. 6—*Selliera radicans* (n = 8), 8^{II}.

FIG. 7—*Mentha cunninghamii* (n = 36), 36^{II}.

FIG. 8—*Scutellaria novae-zealandiae* (n = 30), 30^{II}.

FIG. 9—*Beilschmiedia tarairi* (n = 12), 12^{II}.

FIG. 10—*Phebalium nudum* (n = 16), 16^{II}.

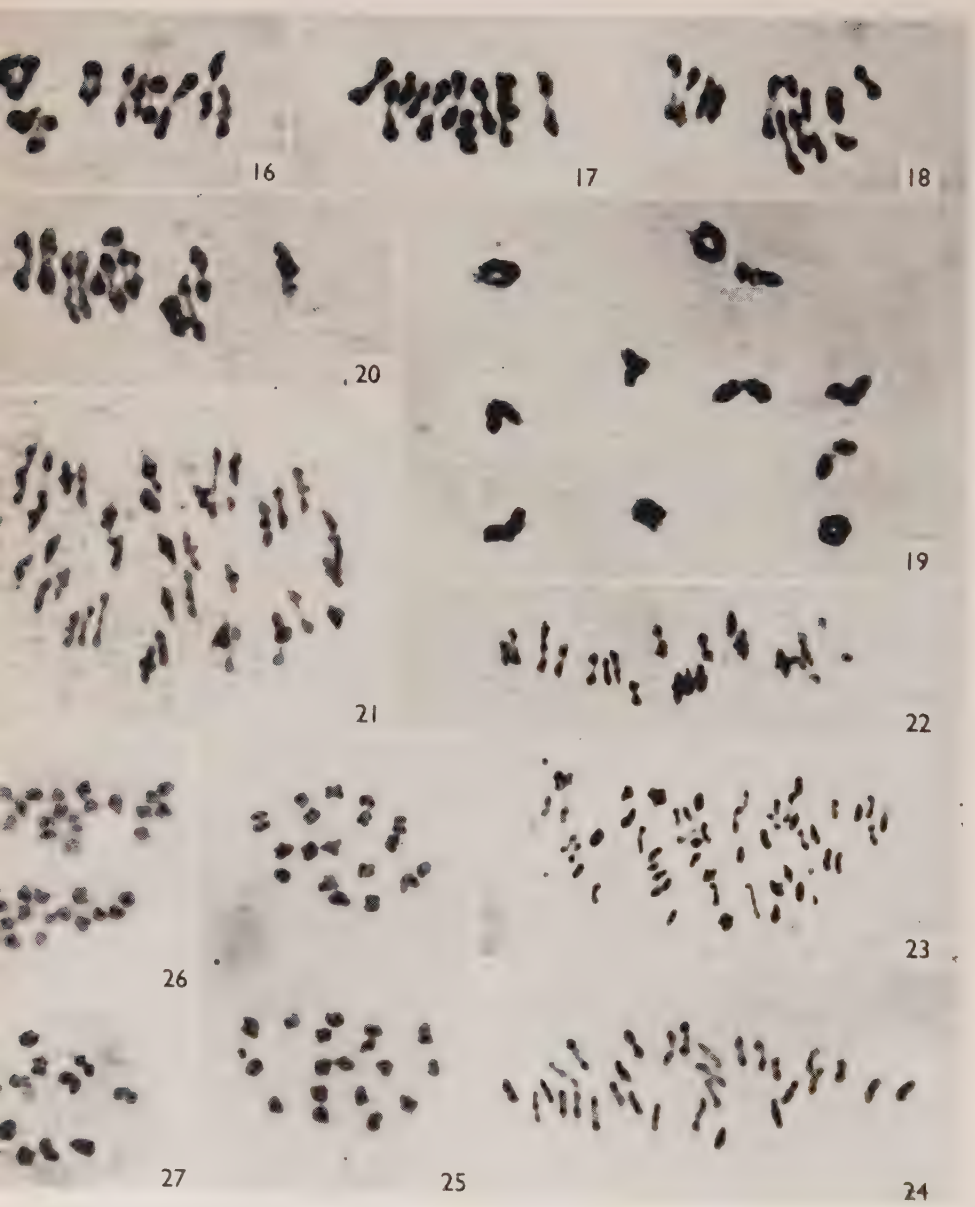
FIG. 11—*Melicope ternata* (2n = 36), mitotic metaphase.

FIG. 12—*M. ternata* var. *mantellii* (n = 18), 18^{II}.

FIG. 13—*M. simplex* (n = 18), 18^{II}.

FIG. 14—*Rumex flexuosus* (n = 20), 20^{II}.

FIG. 15—*R. neglectus* (n = 20), diakinesis, 20^{II}.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Unless otherwise stated, all figures are of first metaphase of meiosis. × 1500.

FIG. 16—*Angelica trifoliolata* (n = 11), 11^{II}.

FIG. 17—*A. geniculata* (n = 11), 11^{II}.

FIG. 18—*A. rosaefolia* (n = 11), 11^{II}.

FIG. 19—*A montana* (n = 11), diakinesis, 11^{II}.

FIG. 20—*Coxella dieffenbachii* (n = 11), 11^{II}.

FIG. 21—*Centella uniflora* (n = 38), 38^{II}.

FIG. 22—*Mazus pumilio* (n = 19), 19^{II}.

FIG. 23—*M. radicans* (n = 52), 52^{II}.

FIG. 24—*Limosella lineata* (n = 30), 30^{II}.

FIG. 25—*Jovellana sinclairii* (n = 18), first anaphase of meiosis.

FIG. 26—*J. repens* (n = 18), first anaphase of meiosis.

FIG. 27—*Australina pusilla* (n = 12), diakinesis, 12^{II}

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30

FIGS. 28–30—First metaphase of meiosis. ×1500.

FIG. 28—*Salicornia australis* (n = 9), 9^{II}.

FIG. 29—*Ackama rosaefolia* (n = 16), 16^{II}.

FIG. 30—*Beilschmiedia tawa* (n = 12), 12^{II}.

A STUDY OF THE PHYSIOLOGY OF *PITHOMYCES CHARTARUM* (Berk. and Curt.) M. B. Ellis*

2. SOME FACTORS INFLUENCING SPORULATION IN CULTURE

By D. J. Ross, Soil Bureau, Department of Scientific and Industrial Research, Wellington

(Received for publication, 13 June 1960)

Summary

Spore production of the fungus *Pithomyces chartarum* (Berk. and Curt.) M. B. Ellis was favoured in media of initial pH 6–7. Similar numbers of spores were produced at 20°C, 24°C, and 28°C.

The effect of autoclaving glucose and nitrogen compounds together was studied in synthetic media.

Spore production appeared to be influenced by the use of mycelial inocula with different sporing capacities.

Spore production was not influenced by the addition of small amounts of hexose-phosphate compounds or copper but was enhanced in some media by the addition of calcium.

Organic nitrogen compounds were necessary for the production of high numbers of spores. High yields could be obtained with several amino acids. A medium containing basal salts, glucose (2.5%) and asparagine (0.25%) yielded two to three times as many spores as a potato-carrot extract medium.

Introduction

Previous studies (Thornton and Ross, 1959; Ross, 1960) showed that *Pithomyces chartarum* (Berk. and Curt.) M. B. Ellis grew more rapidly and produced spores more abundantly on a potato-carrot extract medium than on some chemically defined media. These studies also suggested that toxin was produced more readily on non-defined media (Percival, 1959; Thornton and Ross, 1959).

Factors influencing the production of spores and of toxin are of interest as, in the field, high numbers of spores have been observed in toxic pastures (Thornton and Sinclair, 1960) and it is probable that sheep ingest the fungus mainly as spores. Further experiments have, therefore, been conducted with cultures of *Pithomyces chartarum* to study factors influencing the production of spores and toxin under defined conditions.

Fungi vary in their ability to form spores and many different and apparently unrelated factors have been shown to promote their formation (Hawker, 1957; Morton *et al.*, 1958). The effects of some of these factors on the sporulation of *Pithomyces chartarum* have now been determined.

As it had already been shown that *Pithomyces chartarum* could produce spores on many different carbon and nitrogen substrates (Ross, 1960), a

*Synonymous with *Sporidesmium bakeri* Syd.

more intensive study of some of these subtrates, particularly glucose, nitrate, and asparagine, has been made in a basal salts medium. Trace metals were added, as they enhanced growth and spore production (Ross, 1960). High crop yields of both mycelium and spores have now been produced in synthetic media.

Throughout these investigations, a record has been made of the numbers of spores produced rather than the rate of formation of spores.

The influence of some of these media on the production of toxin will be reported later.

MATERIALS AND METHODS

Organisms

Unless otherwise stated, *Pithomyces chartarum* strain C was used for all experiments. This high-sporing strain was previously disposed by the Commonwealth Mycological Institute, Kew, England, as *Sporidesmium bakeri* Syd. (Hughes, 1953) I.M.I. Herbarium No. 74473. Recently, however, Ellis (1960) revised the genus *Sporidesmium,* and has shown that *Sporidesmium bakeri* should now be included as a synonym of *Pithomyces chartarum* (Berk. and Curt.) M. B. Ellis. As this generic and specific name takes priority over the species *Scheleobrachea echinulata* (Speg.), Hughes proposed by Hughes (1958) to replace *Sporidesmium bakeri* Syd.; the name *Pithomyces chartarum* is used throughout the present work.

A low-sporing strain G was also used in some experiments.

A description of the strains is given by Thornton and Ross (1959) and Ross (1960). The strains were grown on potato-carrot extract agar for 7 days at 25°C and stored at 4°C.

Chemicals

All inorganic compounds and glucose were obtained as ANALAR grade compounds from British Drug Houses Ltd.

L-Asparagine was obtained from B.D.H. Ltd. The other amino acids, fructose, and the dipotassium salt of glucose-1-phosphate were supplied by L. Light and Co. Ltd.

Barium salts of the other organic phosphate compounds were obtained from Sigma Chemical Co. and stored at 4°C.

Media

All media were sterilised at 15 lb/in.^{2} for 15 min.

SYNTHETIC MEDIA

All media contained basal salts solution (Ross, 1960), *viz.* KH_2PO_4, 1·0 g; KCl, 0·5 g; $MgSO_4 \cdot 7H_2O$, 0·5 g; iron, 2·6 p.p.m.; zinc, 0·4 p.p.m.; copper, 0·1 p.p.m.; manganese, 0·05 p.p.m.; molybdenum, 0·04 p.p.m; distilled water, 1l. All synthetic media were adjusted to pH 6·0 before sterilisation.

General media

Unless otherwise stated, media contained glucose (3%) which was added after separate sterilisation.

The concentrations of sodium nitrate or L-asparagine used as sources of nitrogen are reported in the tables.

Media with different amino acids

Amino acids were present in a basal salts-glucose medium (Table 6) at a concentration of 0·0167% N, i.e., equivalent to 0·1% sodium nitrate.

Media containing organic phosphate compounds

Solutions of organic phosphate compounds were prepared as follows and added to the basal salts-glucose-sodium nitrate (0·1%) medium after separate sterilisation.

The dipotassium salt of glucose-1-phosphate was dissolved in water and sterilised by filtration through a Seitz filter.

The barium salts (0·4 g) of glucose-6-phosphate and fructose-1-6-diphosphate were added to 10 ml water containing respectively 0·12 g and 0.15 g of ammonium sulphate and allowed to stand for 24 hr at 4°C. The barium sulphate was then removed and the solutions sterilised by filtration through membrane filters.

The barium salt of 3-glycerophosphoric acid (0·3 g) was boiled under reflux for 3 hr with 10 ml water containing 0·08 g ammonium sulphate and the mixture then filtered through a membrane filter. Glycerophosphoric acid is stable in boiling solutions but the solubility of its barium salt is very low (Umbreit *et al.*, 1951) and the amount of free acid in the present sterile solution was not determined.

Media containing calcium or copper

Calcium ($Ca(NO_3)_2 \cdot 4H_2O$) was added to the synthetic media (Table 8) and copper ($CuSO_4 \cdot 5H_2O$) to potato-carrot extract media before the media were sterilised.

Potato-carrot Extract Medium

A description of this medium is given by Ross (1960).

Cultural Conditions

Culture Vessels

In all experiments with synthetic media, the fungi were grown in 100 ml conical flasks with 20 ml medium.

In experiments with potato-carrot extract media, the fungi were grown in quart bottles with 200 ml medium.

Inocula

As all strains of *Pithomyces chartarum* did not sporulate readily, it was generally more convenient to use mycelial inocula than suspensions of spores

Disks (6 mm diameter) of mycelium were cut from the edge of colonies growing on glucose-nitrate agar (basal salts solution-glucose-sodium nitrate (0·1%)–agar) or from heavily sporing sectors on potato-carrot extract agar. To avoid possible differences arising from inocula, disks for a single experiment were cut from only one or two plates of the same medium. One disk was used for each flask and floated on the surface of the medium with the hyphal side uppermost.

Aqueous suspension of spores were prepared from growth on potato-carrot extract agar. Washed spore suspensions were prepared by washing the spores twice by centrifugation and resuspending in water. After inoculation with these suspensions, cultures contained about 3,000 spores/ml medium.

INCUBATION

Unless otherwise stated, all cultures were incubated in the dark at 24°C.

Measurement of Growth

DRY WEIGHTS

The dry weights of mycelial felts from single flasks were determined as before (Ross, 1960).

SPORE COUNTS

In initial experiments with suspensions of macerated mycelial felts, spores were counted by the conventional technique. Clogging of the pipette, however, sometimes occurred and resulted in low counts. Satisfactory reproducibility was obtained with the following methods which were used throughout this study.

(i) The mycelial felts and fluids from synthetic media were diluted to 100 ml with water containing 1 drop of "Comprox" detergent and macerated for 2 min. in a "Kenmix 55" macerator. The resulting suspensions were further diluted if necessary, e.g., if prepared from media containing asparagine, with water containing "Comprox". All suspensions were then homogenised for 1 min. with a motor-driven "Teflon" homogeniser. As the spores rapidly settled from these homogenised suspensions, a small drop was immediately added with a wide-mouthed pipette to a standard position on a Neubauer counting slide and the coverslip immediately placed in position. Counts were made of spores in 10 × 1 mm squares. Dilutions from the nitrate media usually contained less than 20 spores/1 mm² but dilutions from asparagine media were prepared to contain, if possible, about 30–60 spores/1 mm².

(ii) The mycelial felts and fluids from potato-carrot extract media were diluted to the original volume (200 ml) with water and 2 drops of "Comprox" and macerated for 2 min. in the "Kenmix 55" macerator. Portions (10 ml) of the suspensions were then diluted to 50 ml with water containing 1 drop of "Comprox", homogenised for 1 min. and the spores counted as above.

It should be noted that, by the above methods, counts of spores were about two to three times higher than those obtained by the conventional technique. By the present methods, replicate counts of a single culture or counts of replicate cultures in the same experiment showed coefficients of variation ranging from 10%–18%. The present study was undertaken to find only major effects of different factors on sporulation and the numbers of replicate cultures employed in most experiments were not designed for detailed analyses. Results are presented as mean counts, usually of duplicate cultures.

RESULTS

Influence of Temperature of Incubation

When three strains of *Pithomyces chartarum,* including strain C, were grown on potato-carrot extract agar or potato-glucose agar, spores were produced more rapidly on incubation at 28°C than at 24°C (Ross, 1960). The rate of spore production has not been studied on liquid media at different temperatures, but on potato-carrot extract medium after incubation for 7 days, when maximal yields had probably been attained, the fungus produced similar numbers of spores at 20°C, 24°C, and 28°C (Table 1).

TABLE 1—Influence of Temperature of Incubation

Incubation Temperature (°C)	Crop Yields:	
	Dry Mycelial Felts, mg/ml Culture Fluid	Spores/ml Culture Fluid (multiply figures by 10^4)
20	3.5	209
24	4.1	218
28	3.7	194

Potato-carrot extract medium was inoculated with a spore suspension and the cultures incubated for 7 days.

Influence of pH of Medium

In the potato-carrot extract medium the initial pH had little effect on the numbers of spores produced (Table 2) and an initial pH 6·0 was suitable for sporulation. After growth of the fungus for 21 days in synthetic media the pH values were found to be usually between 6·0 and 7·0 and thus still favourable for spore production.

TABLE 2—Influence of pH of Medium

pH of Medium		Crop Yields	
Initial	After Growth	Dry Mycelial Felts, mg/ml Culture Fluid	Spores/ml Culture Fluid (multiply figures by 10^4)
4.6	6.4	4.5	179
6.0	7.1	4.3	230
8.0	7.3	3.8	207

Potato-carrot extract medium was inoculated with a spore suspension and the cultures incubated for 7 days.

Influence of Inocula

From a culture on potato-carrot extract agar, sub-cultures were prepared on glucose-nitrate agar and potato-carrot extract agar. Disks from these sub-cultures yielded similar numbers of spores when inoculated into basal salts-glucose media (Table 3). Cultures from both agar media, were, therefore, used as inocula in further experiments.

TABLE 3—Influence of Inocula

Medium: Nitrogen Substrate (Concentration, %)	Inoculum: Disks From Growth On	Crop Yields: Spores/ml Culture Fluid (multiply figures by 10^4)
Sodium nitrate (0.1)	Glucose-nitrate agar	25
	Potato-carrot extract agar	31
L-Asparagine (0.079)	Glucose-nitrate agar	117
	Potato-carrot extract agar	107

Influence of Autoclaving Glucose With Nitrogen Compounds

Glucose and amino compounds react to some extent when heated together, causing browning of the medium, and these reaction products have been found, e.g., by Hall (1959), to inhibit growth of some fungi. Although some browning of the present media occurred on autoclaving glucose and asparagine together, growth and spore production of *Pithomyces chartarum* were as satisfactory on these media, and on nitrate media sterilised the same way, as on media in which glucose and the nitrogen compounds had been autoclaved separately (Table 4).

TABLE 4—Influence of Autoclaving Glucose With Nitrogen Compounds

Medium: Nitrogen Substrate (Concentration, %)	Glucose Sterilisation*	Crop Yields: Dry Mycelial Felts, mg/ml Culture Fluid	Crop Yields: Spores/ml Culture Fluid (multiply figures by 10^4)
Sodium nitrate (0.1)†	Separately	8.6	34
	Together	8.5	41
Sodium nitrate (0.25)‡	Separately	8.3	10
	Together	8.0	19
L-Asparagine (0.079)†	Separately	11.2	321
	Together	10.6	285
L-Asparagine (0.25)†	Separately	10.0	393
	Together	10.3	429

*Glucose (3%) was autoclaved either separately from or together with the other components of the medium.

†Disks from potato-carrot extract agar were used as inocula. These media contained calcium (10 p.p.m.).

‡Washed spores were used as inocula.

Influence of Carbohydrates

Previous studies suggested that carbohydrates that supported the production of similar weights of mycelial felts also gave similar numbers of spores (Ross, 1960). This relationship has now been confirmed by the use of fructose and glucose which yielded equal weights of mycelial felts and equal numbers of spores when used at a concentration of 3% in a basal salts-sodium nitrate medium.

Yields of spores in the basal salts-nitrate (0·1%) medium were not greatly influenced by the concentrations of fructose, the numbers produced/ml culture fluid being 12×10^4 with 1·25% fructose and 18×10^4 with 10% fructose.

In the basal salts medium with different concentrations of glucose and sodium nitrate, the yields of spores were again not greatly influenced by the concentrations of glucose although they were somewhat low at high concentrations of glucose and sodium nitrate. Yields of mycelial felts, however, increased with increasing concentrations of glucose; they were not markedly influenced by the amounts of sodium nitrate, except at the highest concentration (Table 5).

TABLE 5—Influence of Concentrations of Glucose and Sodium Nitrate

Glucose Concentration, %*	Crop Yields: Spores/ml Culture Fluid (multiply figures by 10^4) and, in Parentheses, Dry Mycelial Felts, mg/ml Culture Fluid, at Nitrogen Concentrations, N %				
	0.008	0.016	0.04	0.08	0.16
1.25	24 (4.0)	52 (3.5)	65 (3.4)	63 (3.8)	103 (4.0)
2.5	65 (4.7)	46 (6.7)	96 (6.9)	46 (6.9)	68 (7.6)
5.0	103 (10.2)	84 (10.3)	56 (9.9)	35 (7.9)	34 (11.0)
10.0	40 (13.8)	66 (13.2)	70 (17.0)	42 (12.9)	37 (5.8)

*Glucose was added to basal salts solution plus sodium nitrate before sterilisation. Disks from growth on potato-carrot extract agar were used as inocula.

Influence of Nitrogen Compounds

Although *Pithomyces chartarum* grew satisfactorily in a medium with sodium nitrate, it grew more vigorously and produced more spores in media containing some amino acids (Ross, 1960). The enhancement of spore production which resulted from the use of alanine and asparagine (Table 6) has been noted previously with other fungi, *e.g.*, by McDonough and Buston (1956). Leucine and valine were of interest as nitrogen substrates as these acids are components of a "beaker test" compound synthe-

sised by *Pithomyces chartarum* (White, 1958). Although the fungus could utilise these acids, it grew slowly with the production of much submerged mycelium and did not produce large numbers of spores.

TABLE 6—Influence of Nitrogen Compounds

Nitrogen Compound	Crop Yields	
	Dry Mycelial Felts, mg/ml Culture Fluid	Spores/ml Culture Fluid (multiply figures by 10^4)
Sodium nitrate	5·7	16
L-Alanine	7·8	64
L-Asparagine	8·1	83
L-Leucine	10·0	45
L-Valine	11·0	20

Disks from growth on glucose-nitrate agar were used as inocula.

In additional experiments, media containing γ-amino-n-butyric acid or glycine yielded about the same numbers of spores as the asparagine medium.

The influence of different concentrations of glucose and asparagine on growth and sporulation is recorded in Table 7. At glucose concentrations of 5% and 10%, growth was limited when the concentration of nitrogen was 0·016% or less. At all other concentrations of glucose and asparagine the yields of mycelial felts, which were dark brown in colour, were proportional to the amounts of glucose present and a mean yield of 31 mg dry felt was harvested for each 100 mg glucose added to the media. Spore production was also dependent on the concentrations of glucose and asparagine; optimal yields were probably reached at a glucose concentration of *ca* 2·5% and a nitrogen concentration of *ca* 0·04%, i.e., *ca* 0·2% asparagine. Although the pH of some media with high concentrations of asparagine rose to pH 8·3 during growth of the fungus, the pH values of most of the culture fluids were below pH 7 and still favourable for spore production after the 21-day incubation period. At comparable concentrations of glucose and asparagine, the yields of spores were much higher in this experiment than in the experiment reported in Table 5. Similar differences between experiments have been encountered in later studies. At high concentrations ($> 0{\cdot}2\%$) of asparagine, however, spores were always produced at least two to three times more abundantly than on potato-carrot extract medium.

Influence of Phosphate Compounds

Spore production of some fungi has been stimulated by the addition of hexose-phosphates or phosphoglyceric acid (Hawker, 1947; McDonough and Buston, 1956). *Pithomyces chartarum,* however, did not respond to the addition of glucose-1-phosphate, glucose-6-phosphate, fructose-1-6-diphosphate or 3-phosphoglyceric acid at concentrations of 0·025% and 0·05%. Yields of mycelial felts were the same on all media. The mean numbers of spores of strains C and G per ml culture fluid were respectively 70×10^4 and 8×10^4 on media without phosphate compounds and 60×10^4 and 5×10^4 on media with phosphate compounds.

TABLE 7—Influence of Concentrations of Glucose and Asparagine

Glucose Concentration, %*	Crop Yields: Spores/ml Culture Fluid (multiply figures by 10^4) and, in Parentheses, Dry Mycelial Felts, mg/ml Culture Fluid, at Nitrogen Concentrations, % N				
	0.008	0.016	0.04	0.08	0.16
1.25	91 (4.2)	181 (3.6)	354 (4.1)	201 (3.9)	322 (4.0)
2.5	193 (6.7)	417 (8.1)	694 (7.2)	940 (7.9)	558 (7.7)
5.0	164 (10.9)	330 (11.9)	646 (15.2)	652 (16.4)	941 (14.3)
10.0	212 (10.3)	420 (19.4)	870 (25.6)	983 (30.0)	857 (32.7)

*Glucose was added to basal salts solution plus asparagine before sterilisation. Disks from growth on potato-carrot extract agar were used as inocula.

Influence of Calcium and Copper

Stimulation of sporulation of some fungi by calcium has been observed by several workers, e.g., by Campbell (1958), Hadley and Harrold (1958) and Morton *et al.* (1958). In media containing low amounts of nitrogen, the addition of calcium appreciably increased spore production of *Pithomyces chartarum* particularly when disks from glucose-nitrate agar were used as inocula (Table 8). In media containing higher amounts of nitrogen, the effects of adding 10 p.p.m. calcium were not as marked.

TABLE 8—Influence of Calcium

Experiment Number*	Medium: Concentration of Added Calcium, p.p.m.	Crop Yields: Spores/ml Culture Fluid (multiply figures by 10^4) in Medium With Nitrogen Substrate	
		Sodium Nitrate (0.1%)	L-Asparagine (0.079%)
1	0	14	48
	5	13	142
	10	30	188
	20	34	177
	40	43	183
	80	84	184
2	0	29	145
	10	34	321
		Sodium Nitrate (0.25%)	L-Asparagine (0.25%)
3	0	38	409
	10	47	596
4	0	10	393
	10	9	414

*Disks from growth on glucose-nitrate agar were used as inocula in experiment 1 and from potato-carrot extract agar in experiments 2 and 3. Washed spores were used as inocula in experiment 4.

Morton *et al.* (1958) found that sporulation of *Penicillium griseofulvum* was induced by adding copper. The addition of copper, in concentrations up to 25 p.p.m., to the potato-carrot extract medium had no effect on the numbers of spores produced by *Pithomyces chartarum*. At 100 p.p.m. copper, mycelial yields remained unchanged but spore production was approximately halved.

DISCUSSION

Although the rate of spore production of *Pithomyces chartarum* strain C was influenced by temperature (Ross, 1960), the numbers of spores finally produced were similar at 20°C and 28°C.

The pH values of the present media would have been unlikely to limit spore production during growth of the fungus.

In the present synthetic media, good agreement resulted between replicates in a single experiment but appreciable differences were sometimes noted between different experiments. The counts of spores/ml culture fluid were usually below 30×10^4 in media with sodium nitrate and below 200×10^4 in media containing low amounts of asparagine (0·079%). In two experiments, however, mean counts of spores/ml culture fluid were 65×10^4 in media with sodium nitrate and 373×10^4 in a medium with low amounts of asparagine; in these two experiments inocula were obtained from the same agar plates. Although high and low-sporing sectors could be readily distinguished on the same plate of potato-carrot extract agar, macroscopic differences were not easily seen between colonies on different plates of this medium or on glucose-nitrate agar. It would appear, however, that differences did exist and that the variations in these experiments could possibly be due to the use of inocula of different sporing capacities.

Many carbohydrates, including glucose, were suitable for the production of spores (Ross, 1960). Yields of mycelial felts increased with increasing concentrations of glucose but, provided sufficient nitrogen was present in the medium, the fungus did not require more than 2·5% glucose, or fructose, to produce maximal numbers of spores.

Although nitrogen substrates influenced the rate of growth of *Pithomyces chartarum* and the yields of mycelial felts, they had a much greater influence on the production of spores. Yields of spores were low in all media containing sodium nitrate and previous experiments indicated that yields were also low in media containing ammonium salts. The fungus did not grow vigorously or produce many spores in a casamino acid medium (Thornton and Ross, 1959) but it grew well with many different amino acids as sole nitrogen substrates. Spore production was also good in many of these media and it would appear that organic nitrogen compounds were essential to obtain large numbers of spores. Asparagine was amongst the most suitable of the amino acids studied and maximal numbers of spores were produced when its concentration in a glucose medium was 0·2% or greater. Yields of spores in a medium with glucose and high concentrations of asparagine were not influenced by the way in which the medium was autoclaved.

The increase in spore production on the addition of trace metals (Ross, 1960) can probably be attributed to the action of zinc which has a stimulatory effect on many fungi. The numbers of spores did not increase with increasing concentrations of copper. Little is known of the role of calcium in fungal metabolism (Davies, 1959), but the demonstration of its beneficial effect on the sporulation of *Pithomyces chartarum* depended on the concentrations of nitrogen compounds in the media.

The rates of mycelial growth and spore production were slower on synthetic than on non-defined media but in many of the synthetic media more spores were finally obtained than from the potato-carrot extract medium. Even greater numbers of spores, however, were produced (Thornton and Ross, unpublished data) on the moistened rye grain medium described by Lloyd and Clarke (1959). On this rye grain medium, the fungus could grow over a large surface area. Morton *et al.* (1958) state that exposure of a fungus to subaerial conditions is a very powerful factor in inducing sporulation and it is possible that spore production of *Pithomyces chartarum* could be further enhanced on liquid synthetic media by the use of more shallow layers of medium in the culture vessels.

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THE PRESERVATIVE TREATMENT OF *PINUS RADIATA* TIMBER BY PRESSURE IMPREGNATION

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Summary

The results obtained from the chemical determinations of the quantity of preservative in *Pinus radiata* timber which had been pressure preservatised in two commercial treatment plants are discussed. In evaluating the results of the treatment, use has been made of the core to cross sectional loading relationship described by other New Zealand workers.

The pattern of treatment between the two plants was found to be very similar despite the different operating conditions existing Significant correlations were found between solution absorption and timber moisture content both in respect to the charge and to the individual stick variations, and between solution absorption and basic density of the individual sticks within a charge. Complete penetration with a very uniform distribution of preservative was, however, achieved in all cases, and control of the salt loading could be maintained by the adjustment of preservative solution concentrations.

Introduction

A number of papers, based on laboratory work, have been published in this country concerning the pressure preservative treatment of various wood species. In these papers Harrow 1950, 1951a, and 1951b describes the results obtained from the pressure impregnation of the native timbers rimu, matai, and tawa and the exotic *Pinus radiata.* The evaluation of the results of this work has been based on the retention of preservative in the "core" of the cross-section of the timber and the relationship between this core retention and that obtained in the overall cross-section, the core area being taken as the central one ninth of the complete cross sectional area. Preservative loadings were obtained by chemical analysis of samples of the treated timber.

The same criteria of treatment efficiency, that is core loading and the relationship between it and the overall retention have been used in the interpretation of the results obtained in the present study of commercial treatments. The paper describes an investigation of the standard of treatment at two commercial pressure preservation plants using a multi-salt water-borne preservative. The timber treated was milled from *Pinus radiata* grown in plantations on the volcanic plateau area of the North Island.

Materials and Methods

This investigation was commenced at the Pinedale preservation plant of N.Z. Forest Products Ltd. and later was extended to include the Kinleith plant. Impregnation of all sizes of sawn timber (*P. radiata*) is carried out at both plants using a full-cell, vacuum-pressure-vacuum cycle at atmo-

spheric temperature. The former plant operates at a maximum pressure of 100 p.s.i. and the latter at 275 p.s.i. The major volume of the timber treated is air-dried before impregnation, the small remaining portion being kiln dried. Treatment at both plants is carried out to refusal point which, in practice, is arbitrarily defined as the point when the rate of solution absorption into the complete charge of timber has fallen to between one and two gallons per minute dependent on the volume of the charge.

Table 1 sets out typical cycles for the impregnation of charges of timber at the Pinedale and Kinleith plants.

TABLE 1

	Pinedale Plant	Kinleith Plant
Date	30/5/56	9/5/57
Preservative	Acid-cupric-chromate and boric acid	Acid-cupric-chromate and boric acid
Timber species	Radiata pine	Radiata pine
Moisture content at time of treatment (% O.D. basis)	24%	20%
Size	4 in. × 2 in.	4 in. × 2 in.
Volume of charge	600.58 cu. ft.	415.25 cu. ft.
Initial vacuum and time held	26 in. Hg. 5 min.*	26 in. Hg. 5 min.*
Treating pressure and time held	100 p.s.i. 152 min.*	275 p.s.i. 87 min.*
Final vacuum and time held	25 in. Hg. 5 min.*	26 in. Hg. 20 min.*
Volume of solution used	2,235 gallons	1,590 gallons
Strength of solution	1.74%	1.52%
Absorption per cubic foot	3.7 gallons	3.8 gallons
Retention of preservative	0.65 lb./cu. ft.	0.58 lb./cu. ft.
Total treatment time	8 hr 59 min	2 hr 41 min

*Not including time required to achieve maximum vacuum, or pressure or the period for filling and emptying of cylinders with solution. Considerable differences exist between the two plants in the times required to carry out these various phases of the operation, longer periods being required at the Pinedale plant.

Over the period that each plant was studied charges of 4 in. × 2 in. stock were sampled at more or less regular intervals (mean six weeks). Thus it was possible to obtain a general picture of treating conditions throughout the year.

From each of these charges ten or eleven sapwood lengths were removed prior to treatment. Each of the selected lengths had a piece about one foot long docked from either end prior to treatment for use in density determination. The weight and nominal volume of the shortened lengths which ranged in length from 8–20 ft were determined. Cross sectional and core moisture content figures were obtained either by oven drying samples or by the use of a resistance type moisture meter. Sapwood content of the samples was determined in the laboratory by applying a heartwood stain to the density blocks. Lengths which showed more than a very small portion of heartwood were not considered in the following study. After the samples had been prepared they were loaded along with the timber for the charge in which they were to be included, into the cylinder ready for treatment in the normal manner.

All treatments were carried out using the preservative acid-cupric-chromate and boric acid (Celcure), a sample of which was taken during the course of each treatment for chemical analysis.

After withdrawal of the charge from the pressure cylinder uptake of solution and salt retention of the individual sample lengths were obtained by—

1. Reweighing and calculating pick up from the weight increase and volume of each stick, and
2. Cutting out a short piece of clear wood for chemical analysis from near mid-length of each stick.

In the latter case core retentions were also obtained. These analyses were carried out, in duplicate, for the copper component of the preservative.

RESULTS

This investigation covers the results of the examination of 186 individual lengths of 4 × 2 in. timber treated over 19 commercial charges (9 from Pinedale and 10 from Kinleith).

Tables 2 and 3 set out the mean sample figures on a charge basis for the respective treatment plants. Included in the tables are the physical measurements taken prior to treatment together with the various absorption and loading figures of the treated lengths.

The more detailed individual stick results are included as an appendix.

In the case of the cross sectional salt retentions, the loadings obtained from both methods of assessment (see above) have been included. Comparison of these two sets of figures shows that generally there is reasonable agreement; in certain charges, however, marked differences are evident. References to cross section retentions in the following discussion refer to the analytical results as it is considered that they represent a closer approach to the true salt loadings obtainable in clear sapwood.

Neither moisture content nor density was found to differ significantly between the two plants, nor did average density differ significantly from charge to charge. However, on a charge basis moisture content did vary significantly and was found to account for 65% of the variation in the solution absorption between charges ($r = -0{\cdot}804$. Significant at 0·001 level).

When individual lengths are considered it was found that the "within charge" density range was quite large and its effect on absorption was just as important as the restricted moisture content although neither explain more than a small part of the variation found from stick to stick within each charge.

Differences in solution absorption on a charge basis were found to be highly significant, even when the effects of moisture content and density are taken into account. There was no significant difference between the two plants.

Analyses of variance on the core to cross section loading ratios showed that both plant and charge means vary very significantly.

TABLE 2—Mean Data Relating to Preservative Treatments

Pinedale Plant Results

Charge No. and Date	No. of Samples	Moisture Content (% o.d. Weight)		Basic Density (lb/cu. ft.)	Solution Absorption (lb/cu. ft.)	Salt Loadings (lb/cu. ft.)			Ratio Core/ Overall Loading (From Analytical Results)
						Cross Section		Core	
		Core	Cross Section			By Weight Pick Up, Wood Volume, and Solution Strength	By Analysis and Density	By Analysis and Density	
1. 25/1/56	10	22	22	26·1	41·2	0·620	0·611	0·484	0·788
2. 20/2/56	9	21	20	26·2	41·6	0·647	0·634	0·522	0·822
3. 13/3/56	10	19	18	27·6	41·2	0·667	0·669	0·524	0·780
4. 11/4/56	10	22	26	24·4	43·3	0·709	0·700	0·556	0·793
5. 1/5/56	9	21	19	26·5	42·5	0·654	0·675	0·547	0·810
6. 30/5/56	9	26	32	25·3	36·8	0·618	0·602	0·488	0·810
7. 21/6/56	11	28	47	26·9	29·2	0·512	0·516	0·440	0·850
8. 8/11/56	7	31	23	26·5	39·3	0·648	0·641	0·497	0·776
9. 4/12/56	11	34	24	25·3	41·1	0·667	0·642	0·522	0·813
Means	..	25	26	26·1	39·6	0·638	0·632	0·509	0·805

TABLE 3

Kinleith Plant Results

1. 13/9/56	11	27	23	25·6	41·1	0·622	0·614	0·542	0·885
2. 10/10/56	11	26	23	25·7	39·3	0·697	0·673	0·636	0·946
3. 5/12/56	9	24	20	27·6	38·6	0·572	0·640	0·495	0·857
4. 19/12/56	10	30	26	26·7	38·9	0·582	0·621	0·544	0·880
5. 7/3/57	10	19	16	26·4	41·9	0·567	0·635	0·532	0·836
6. 3/4/57	10	16	16	26·5	41·7	0·592	0·681	0·605	0·891
7. 9/5/57	9	25	21	25·5	41·2	0·534	0·564	0·490	0·868
8. 13/6/57	10	26	24	25·3	40·4	0·663	0·564	0·483	0·852
9. 7/9/57	10	31	25	25·4	36·5	0·656	0·656	0·557	0·848
10. 16/10/57	10	32	25	25·6	39·4	0·697	0·644	0·534	0·819
Means	..	26	22	26·1	39·9	0·618	0·629	0·542	0·868

DISCUSSION

Before considering the results obtained in this investigation it should be re-emphasised that the work was carried out on one species of timber grown in one locality, albeit that this locality was composed of some 150,000 acres of forest. It should also be borne in mind that the investigation was planned with the object of obtaining reliable information on the results that are secured from normal commercial operation. Control of the variables, therefore, both in the treating procedure and in the material sampled was related to the complete charge rather than to the individual samples.

Between Plant Variation

Despite the fairly wide differences in the operating conditions and schedules between the two plants (Table 1) it can be seen from Tables 2 and 3 that the general standard of treatment is very similar.

As already indicated, neither the moisture content nor the density "between plant" differences is significant. The very close agreement between the mean solution absorption figures (39·6 and 39·9 lb/cu. ft. respectively) is therefore probably due to the practice of continuing treatments "to refusal" resulting in the voids in the wood becoming more or less completely filled with preservative solution. This high solution absorption is also evident from the uniformity of the salt distribution throughout the cross section as indicated by the high core to overall salt ratios obtained. It appears in the case of the Pinedale plant that the uniformity of salt distribution is achieved, in spite of the relatively low treating pressure, by virtue of the extended pressure period the timber is given. In the case of Kinleith somewhat higher results are obtained by the use of a high treating pressure for a short time (Table 1).

Between Charge Variation

It is evident from the data presented in Tables 2 and 3 that there may be considerable variations in solution uptake from charge to charge within each plant. It is from the pretreatment estimate of these absorptions followed by the adjustment of the solution concentration that results in the specified salt loading being obtained. Of the physical properties affecting these absorptions moisture content of the timber has undoubtedly the greatest effect as is evident from the writing in of an upper moisture limit clause in all pressure treatment specifications.

As has been outlined previously the data on a 'charge basis' indicated that there was a highly significant correlation between cross section moisture content and absorption, moisture content accounting for approximately 65% of the absorption variation. The actual prediction equation is

$$y - 3{\cdot}98 = -0{\cdot}0491\ (x - 24)$$

where x = cross section moisture content in %

and y = absorption in lb./cu. ft.

Moisture content alone did not, however, account for enough of the variation to make prediction by this means very useful. An indication of the possible variation is given by the 95% confidence intervals at selected moistures.

$x = 16\%$	$y = 4{\cdot}37 \pm {\cdot}59$ gal./cu. ft.
24	$3{\cdot}98 \pm {\cdot}54$
47	$2{\cdot}85 \pm {\cdot}68$

The effect of incorrect solution adjustment can be seen in Kinleith charges 7 and 8 (table 3) where despite high solution uptakes and normal core/cross section ratios, low salt loadings have resulted from too low solution concentrations.

In normal air and kiln dried timber there is usually a moisture gradient throughout the cross section, the highest moisture being usually in the core. However, as can be seen the slope of this gradient varies from charge to charge depending to a large extent on the drying rate and on the final moisture content. In all charges with the exception of Kinleith 5 and 6 which consisted of kiln dried material, the timber had come from air dried stock. In the case of Pinedale charges 4, 6, and 7, rain wetting immediately prior to treatment had reversed this normal gradient but in only the severest case (charge 7) where the mean cross sectional moisture content rose to 47%, had it greatly reduced the absorption achieved (29·2 lb./cu. ft.). The mean core to overall salt ratio of this charge remained, however, at a level comparable with that found in normal air dried material. Anticipation of the low absorption in such a case by an increase in solution concentration would therefore assure a satisfactory treatment.

Although on a charge basis significant differences were shown to exist in the salt ratios it can be seen that over the moisture range encountered the mean values are not widely spread being from 0·771–0·850 for Pinedale and from 0·819–0·946 for Kinleith.

As might be expected from random sampling of sapwood lengths, the charge to charge density variation was found to be insignificant and could not be shown to be a factor of the charge absorption differences.

Within Charge Variation

On comparing the results on the basis of the individual lengths as set out in the accompanying appendices, differences in salt loading and salt distribution are seen to be present between lengths of similar moisture content treated in the same charge. Significant correlations were found between moisture content and absorption and also between basic density and absorption, indeed it was shown that the unrestricted, widely scattered basic density figures were just as important as moisture content in relation to solution uptake differences within a charge. However, although both correlations were significant, their combined effect explained only a small part of the stick to stick variation.

Among factors which were not examined but which could collectively account for much of the remaining variations between sticks are the various

inherent structural differences that are present from tree to tree. It is also known that the angle of sawing in respect to the growth rings has some relation to the ease of solution penetration into the timber. Despite these various factors which combine to introduce differences in the treatability of the individual lengths, it can be seen that with one exception the salt ratios are exceptionally high indicating a relatively uniform distribution of salt throughout the cross sections. The anomalous ratio of 0·356 obtained for sample 8, charge 10, Kinleith cannot be explained. In the case of charge 7, Pinedale, where the sample lengths had been severely rain wetted prior to treatment the lowest ratio was 0·735 (No. 9) while the length with the highest cross sectional moisture content (58%) had a core to overall salt ratio of 0·867. It would appear therefore that considerable variations in moisture content could occur without altering greatly the salt ratios.

General

The opinion has been expressed by Harrow (1951a) on the basis of his laboratory studies that "even with complete penetration, the core loading may be only half as great as the average loading of treated pine."; and again (1954) " . . . with an efficient treating plant, the core loading may be only one-fifth of the average loading of a charge of timber." It is not possible to compare directly the published results with those obtained in the present investigation. However, it has been shown in the case of sapwood *P. radiata* treated under the commercial conditions described that higher relative core retentions than those referred to above can be regularly achieved.

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APPENDIX 1

Pinedale Plant Results

Charge No., Date, and Sample No.		Moisture Content (% o.d. Weight)		Basic Density (lb/cu. ft.)	Solution Absorption (lb/cu. ft.)	Solution Strength %	Salt Loadings (lb/cu. ft.)			Ratio Core/ Overall Loading (From Analytical Results)
		Core	Cross Section				Cross Section		Core	
							By Weight Pick Up, Wood Volume, and Solution Strength	By Analysis and Density	By Analysis and Density	
(1)	1	25	22	25·2	4·38	1·505	·659	·564	·690	·869
25/1/56	2	24	22	27·6	4·16		·626	·696	·511	·734
	3	17	20	26·1	3·60		·542	·489	·293	·599
	4	22	22	28·1	4·12		·620	·592	·548	·926
	5	20	21	23·1	4·47		·673	·590	·389	·659
	6	24	23	31·1	3·13		·472	·577	·417	·723
	7	20	21	24·6	4·47		·672	·686	·564	·822
	8	19	21	27·1	4·33		·651	·616	·492	·799
	9	25	25	23·4	4·31		·648	·647	·562	·869
	10	25	23	24·4	4·25		·639	·650	·572	·880
(2)	1	18	19	25·2	4·41	1·557	·687	·675	·530	·785
20/2/56	2	21	19	23·7	4·42		·688	·628	·502	·799
	3	21	19	30·1	4·06		·632	·633	·599	·820
	4	23	21	27·1	4·03		·627	·630	·507	·805
	5	21	19	25·6	4·29		·668	·616	·486	·789
	6	24	22	30·2	3·72		·579	·602	·473	·786
	7	20	19	26·3	4·19		·652	·635	·517	·814
	8	22	20	23·9	3·92		·610	·572	·495	·865
	9	22	21	23·6	4·36		·679	·712	·660	·935
(3)	1	23	19	25·5	4·22	1·169	·683	·728	·537	·738
13/3/56	2	20	18	25·8	4·34		·702	·749	·674	·900

	3	15	17	26·9	4·12		·667	·593	·480	·809
	4	17	17	26·9	3·95		·640	·591	·426	·721
	5	19	17	29·4	3·72		·602	·659	·552	·838
	6	19	17	30·5	3·95		·640	·694	·587	·846
	7	19	18	28·5	4·15		·672	·679	·530	·781
	8	19	18	28·9	4·28		·693	·678	·508	·749
	9	19	18	24·7	4·33		·701	·683	·542	·794
	10	20	18	28·5	4·12		·667	·637	·399	·626
(4)	1	24	26	23·9	4·45	1·647	·733	·721	·525	·728
11/4/56	2	25	28	25·8	4·22		·695	·704	·559	·794
	3	24	29	21·4	4·43		·730	·738	·558	·756
	4	23	29	27·6	4·29		·706	·654	·450	·688
	5	17	25	22·7	4·89		·805	·719	·643	·894
	6	24	25	24·6	4·03		·664	·739	·609	·812
	7	20	24	24·5	4·08		·671	·717	·608	·848
	8	22	29	23·6	4·30		·708	·750	·622	·829
	9	25	25	25·8	3·97		·654	·648	·509	·785
	10	19	22	24·4	4·39		·723	·605	·481	·795
(5)	1	19	20	28·5	4·16	1·540	·641	·660	·491	·744
1/5/56	2	23	20	27·2	4·14		·637	·680	·535	·787
	3	21	19	26·4	4·27		·657	·705	·595	·844
	4	21	20	26·3	4·32		·665	·738	·596	·808
	5	21	19	28·5	4·09		·630	·612	·546	·892
	6	19	19	25·7	4·40		·678	·669	·546	·816
	7	19	19	25·1	4·48		·690	·683	·547	·801
	8	22	19	27·8	4·12		·635	·648	·500	·772
	9	23	20	23·3	4·23		·652	·678	·565	·830
(6)	1	25	36	23·8	3·62	1·666	·603	·645	·582	·902
30/5/56	2	22	38	22·5	3·57		·594	·574	·488	·850
	3	26	30	24·6	3·82		·636	·619	·549	·887
	4	24	26	27·1	3·88		·646	·619	·560	·905
	5	26	32	23·4	3·87		·645	·589	·477	·810
	6	29	36	24·9	3·51		·585	·537	·435	·810
	7	27	28	29·2	3·70		·616	·649	·500	·770
	8	27	34	27·2	3·58		·596	·592	·386	·652
	9	27	32	25·0	3·60		·600	·598	·419	·701

APPENDIX 1—*continued*

Pinedale Plant Results—continued

Charge No., Date, and Sample No.		Moisture Content (% o.d. Weight)		Basic Density (lb/cu. ft.)	Solution Absorption (lb/cu. ft.)	Solution Strength %	Salt Loadings (lb/cu. ft.)			Ratio Core/ Overall Loading (From Analytical Results)
		Core	Cross Section				Cross Section		Core	
							By Weight Pick Up, Wood Volume, and Solution Strength	By Analysis and Density	By Analysis and Density	
(7)	1	28	48	27·4	2·82	1·752	·494	·460	·399	·861
21/6/56	2	27	45	26·9	2·85		·499	·462	·405	·877
	3	29	53	29·4	2·82		·494	·571	·552	·932
	4	31	55	28·9	2·98		·522	·575	·546	·950
	5	29	58	25·4	2·51		·440	·472	·409	·867
	6	28	51	26·4	2·87		·503	·559	·499	·893
	7	25	39	28·1	3·00		·526	·498	·324	·651
	8	30	46	24·5	3·02		·829	·527	·509	·966
	9	30	40	28·1	3·14		·550	·514	·378	·735
	10	29	47	24·6	3·45		·601	·559	·460	·823
	11	26	36	26·4	2·69		·471	·475	·375	·789
(8)	1	38	25	27·1	3·94	1·648	·649	·668	·493	·738
8/11/56	2	30	21	24·9	3·89		·641	·624	·423	·678
	3	29	24	28·7	3·91		·644	·664	·475	·715
	4	30	22	27·3	3·64		·600	·588	·482	·820
	5	33	25	22·8	4·26		·702	·636	·535	·841
	6	26	21	26·2	4·11		·667	·686	·554	·808
	7	31	24	28·7	3·76		·620	·621	·517	·833
(9)	1	32	23	25·5	4·14	1·620	·671	·632	·581	·919
4/12/56	2	40	25	25·0	3·78		·612	·570	·515	·904
	3	30	23	29·6	3·76		·609	·613	·429	·700

4	34	23	25·3	4·30	·697	·637	·479	·752
5	31	23	22·8	4·44	·719	·651	·497	·763
6	38	24	25·8	4·05	·656	·667	·558	·837
7	35	24	25·2	4·48	·726	·672	·527	·784
8	33	25	24·4	4·03	·653	·624	·603	·966
9	39	24	25·2	3·98	·645	·720	·621	·863
10	38	24	26·2	4·16	·674	·651	·496	·762
11	28	22	23·4	4·14	·671	·627	·433	·691

APPENDIX 2

Kinleith Plant Results

Charge No., Date, and Sample No.		Moisture Content (% o.d. Weight)		Basic Density (lb/cu. ft.)	Solution Absorption (lb/cu. ft.)	Solution Strength %	Salt Loadings (lb/cu. ft.)			Ratio Core/ Overall Loading (From Analytical Results)
							Cross Section		Core	
		Core	Cross Section				By Weight Pick Up, Wood Volume, and Solution Strength	By Analysis and Density	By Analysis and Density	
(1)	1	26	23	24·3	4·57	1·513	·691	·672	·599	·891
13/9/56	2	25	21½	23·2	4·33		·655	·586	·580	·990
	3	26	22½	26·1	4·19		·634	·636	·517	·813
	4	24½	21½	25·4	3·98		·602	·600	·543	·905
	5	31	24	24·2	4·54		·687	·645	·529	·820
	6	24½	21	25·8	4·38		·663	·634	·556	·877
	7	27	22½	24·3	3·86		·584	·479	·424	·885
	8	35½	24½	28·2	4·41		·667	·598	·522	·873
	9	28	23	27·4	2·97		·449	·644	·509	·790
	10	25	22	24·7	4·35		·658	·696	·701	1·007
	11	27½	23	27·9	3·67		·555	·540	·479	·887
(2)	1	25	23	27·5	3·59	1·774	·637	·645	·651	1·009
10/10/56	2	26	23½	27·9	4·14		·734	·693	·795	1·147
	3	29	26	27·1	3·53		·626	·560	·539	·963
	4	25½	24	27·0	3·45		·612	·666	·520	·781
	5	29	23½	23·4	4·38		·777	·725	·630	·869
	6	24	22	24·4	4·35		·772	·734	·707	·963
	7	27	23	25·0	3·85		·683	·673	·591	·878

	8	25	23½	22·6	4·12		·731	·726	·749	1·032
	9	28½	24	28·1	3·59		·637	·609	·506	·831
	10	26	23½	23·4	4·19		·743	·626	·676	1·080
	11	24	21	26·2	4·03		·715	·742	·635	·856
(3)	1	24	20	26·6	4·12	1·484	·611	·660	·550	·833
5/12/56	2	22½	19	27·2	3·64		·540	·662	·560	·846
	3	22½	19	26·1	4·01		·595	·717	·576	·803
	4	24	19	28·2	3·78		·561	·613	·519	·847
	5	23	18	24·3	4·26		·632	·637	·572	·898
	6	24	17½	24·9	4·21		·625	·659	·586	·889
	7	26½	22½	28·8	3·68		·546	·628	·545	·868
	8	25	20½	31·2	3·57		·530	·572	·502	·878
	9	24	19½	31·5	3·44		·510	·614	·525	·855
(4)	1	31	27	24·3	4·40	1·495	·658	·618	·561	·908
19/12/56	2	25	24	25·8	3·98		·595	·607	·579	·954
	3	32½	31	27·6	3·87		·579	·626	·527	·842
	4	27	23	30·8	3·92		·586	·649	·488	·752
	5	27	23½	27·9	3·99		·597	·637	·571	·896
	6	25½	23½	26·2	3·94		·589	·616	·591	·959
	7	35½	28½	24·7	3·05		·456	·607	·586	·965
	8	Rain wetted		24·1	4·00		·598	·651	·586	·900
	9	33½	25½	26·6	3·98		·595	·626	·534	·853
	10	Rain wetted		29·1	3·80		·568	·569	·440	·773
(5)	1	19	16	26·4	4·23	1·353	·572	·622	·578	·929
7/3/57	2	18½	15½	28·8	3·92		·530	·661	·539	·815
	3	19½	17½	26·3	4·09		·553	·669	·557	·833
	4	19	17½	25·1	4·50		·609	·643	·507	·788
	5	19½	17	29·2	3·16		·428	·563	·463	·822
Kiln Dried	6	19	16	24·7	4·39		·594	·679	·576	·848
	7	17	15	24·9	4·56		·617	·655	·605	·924
	8	19	17	27·1	4·20		·568	·630	·534	·848
	9	20	17	25·2	4·37		·591	·623	·507	·814
	11	18	15	25·9	4·46		·603	·607	·451	·743

APPENDIX 2—*continued*

Kinleith Plant Results—continued

Charge No., Date, and Sample No.		Moisture Content (% o.d. Weight)		Basic Density (lb/cu. ft.)	Solution Absorption (lb/cu. ft.)	Solution Strength %	Salt Loadings (lb/cu. ft.)			Ratio Core/ Overall Loading (From Analytical Results)
							Cross Section		Core	
		Core	Cross Section				By Weight Pick Up, Wood Volume, and Solution Strength	By Analysis and Density	By Analysis and Density	
(6)	1	15	13	24·0	4·27	1·419	·606	·612	·608	·993
3/4/57	2	14½	14	26·5	4·38		·622	·703	·588	·836
Kiln Dried	3	15½	14½	30·7	3·93		·558	·696	·636	·914
	4	14	14½	25·7	4·53		·643	·752	·526	·699
	5	16	16	24·5	4·45		·631	·679	·591	·870
	6	17	17	23·4	3·59		·507	·628	·509	·811
	7	15½	15	24·7	4·25		·603	·634	·553	·872
	8	15	14½	27·7	4·19		·595	·685	·690	1·007
	9	19	19½	27·0	3·96		·562	·720	·636	·883
	10	19½	17	30·3	4·17		·592	·699	·714	1·021
(7)	1	24	20	26·6	3·90	1·439	·561	·455	·400	·879
9/5/57	2	22	20½	23·7	4·12		·593	·578	·406	·702
	4	33	20	24·5	4·20		·606	·587	·601	1·024
	5	23	20	23·2	4·12		·593	·636	·569	·895
	6	22	20	22·4	4·22		·607	·609	·494	·811
	7	26	23	25·4	3·93		·566	·534	·442	·828
	8	27	25	28·7	3·63		·522	·548	·472	·861
	9	26	23	24·5	4·67		·672	·620	·577	·931
	10	22	16	30·4	4·28		·616	·512	·452	·883

(8)	1	25½	24	23·0	4·21	1·642	·691	·568	·452	·796
13/6/57	2	24	22½	27·7	3·34		·548	·502	·462	·920
	3	24½	23	28·8	5·54		·909	·539	·469	·870
	4	25½	23½	27·6	3·83		·629	·603	·559	·927
	5	27	25	23·4	4·02		·660	·628	·587	·935
	6	25	24	25·4	3·99		·655	·598	·491	·821
	7	25½	24	25·4	4·65		·764	·600	·489	·815
	8	25½	24½	23·9	3·90		·640	·599	·551	·920
	9	27	25	24·2	3·92		·644	·553	·492	·890
	10	26½	24½	24·0	2·96		·486	·477	·278	·622
(9)	1	29	24	28·0	3·69	1·797	·663	·646	·525	·813
7/9/57	2	30½	24	28·9	3·84		·690	·658	·501	·761
	3	25	23½	26·5	3·91		·703	·718	·673	·937
	4	28	25	21·9	4·27		·767	·626	·472	·754
	5	33	24	25·3	4·16		·748	·554	·484	·874
	6	41½	30	23·3	2·80		·503	·602	·535	·889
	7	26	23	25·0	2·03		·365	·720	·613	·851
	8	33½	26	26·8	3·28		·589	·704	·610	·866
	9	29½	24	24·2	4·29		·771	·661	·571	·864
	10	33½	25	24·3	4·22		·758	·674	·588	·872
(10)	1	32½	23½	23·5	5·71	1·770	1·010	·665	·628	·944
16/10/57	2	29½	23	28·4	3·73		·660	·651	·583	·896
	3	28	23	26·2	3·89		·688	·659	·582	·883
	4	28	23	22·5	3·43		·607	·647	·662	1·023
	5	35½	24½	26·1	3·99		·706	·660	·490	·742
	6	37	24½	27·9	3·82		·674	·641	·528	·824
	7	34½	25	22·3	3·77		·666	·578	·457	·791
	8	25½	23½	26·9	3·32		·587	·528	·188	·356
	9	40	24	24·7	4·09		·724	·666	·587	·881
	10	31½	23½	27·2	3·65		·646	·742	·632	·852

VARIATION IN LEAF ANATOMY IN *Festuca novae-zelandiae (Hack.) Cockayne, AND F. matthewsii (Hack.) Cheeseman*

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Summary

Anatomical characters seen in transverse section of the leaf have been extensively used as taxonomic criteria in *Festuca,* and these have been examined in detail in two species indigenous to New Zealand, *F. novae-zelandiae* and *F. matthewsii.* Sections were made from some hundreds of plants grown in the relatively uniform environment of the Botany Division experimental gardens and compared with those from herbarium specimens. Abundant variation was found in such characters as the number of vascular bundles, number of ridges, distribution and amount of subepidermal abaxial sclerenchyma, frequency and position of adaxial sclerenchyma in the ridges, attachment of vascular bundles to abaxial sclerenchyma (girders), and supra-fascicular sclerenchyma. No ecological or geographic grouping of variation patterns was evident.

Developmental patterns within a leaf are described and histological gradients are evident. Within-plant variation is often high. It is concluded that anatomical characters seen in leaf section in these two species are for the greater part unusable as specific diagnostic characters, as the two species show similar variation patterns.

INTRODUCTION

Hackel (1882) in his monograph on European fescues used leaf anatomy as one of his five principles in species recognition and has been followed extensively since that date, more particularly by St Yves (1927), and Howarth (1928). Burr and Turner (1933), involved in the problem of recognising species of British grasses in the vegetative condition, state that there is considerable modification of many of the "so-called characteristic features" in the vegetative condition when plants are grown in close association or subject to continual grazing, cutting, or hard usage. They stated that " . . . a search has been made for a more certain means of diagnosis and has been found in the anatomy of the leaf as portrayed in transverse section". The obvious inference is that the anatomy of the leaf is not modified by those conditions which modify vegetative characteristics.

Metcalfe (1955) in discussing his work on the systematic anatomy of the monocotyledons states under Gramineae, *inter alia,* that in the transverse section of a leaf both the occurrence and distribution of sclerenchyma especially in relation to the vascular bundles and the shape of the lamina are *specific diagnostic characters.* More recently, however, Mr C. E. Hubbard of Kew is reported by Ballard (1957) as stating at a meeting of the British Association at Dublin that the amount and arrangement of sclerenchymatous tissue is probably of ecological significance only.

At the Botany Division, D.S.I.R., Mr V. D. Zotov has been examining leaf sections in *Festuca* during a number of years. His sections have been from field collections and his drawings of these sections frequently accompanied the herbarium specimens. Variation in leaf anatomy had been frequently discussed with Mr Zotov, and any quick examination of his drawings reveals abundant variation. The unpublished data available from these section drawings were made readily available for comparative work.

As part of a study on some aspects of tussock grasses, a large collection of *Festuca novae-zelandiae* and *F. matthewsii* had been assembled of material raised from seed collected in the wild. This collection of about 5,000 plants of *F. novae-zelandiae* from 54 localities and *F. matthewsii* from 15 localities was grown in the relatively uniform environment of the Botany Division experimental gardens at Lincoln, Canterbury. Samples were taken from this collection to test the validity of anatomical characters as taxonomic ones. Hackel (*op. cit.* p. 29) had already warned that histological characters, as all others, must be tested for variation and constancy within each species or group, though there is little published evidence of tests being conducted.

Festuca novae-zelandiae is a widespread physiognomically important plant in the tussock grasslands of New Zealand. *Festuca matthewsii*, previously thought to be of limited range (Cheeseman, 1925), and not mentioned in Cockayne's Vegetation of New Zealand (1928), has been recently found to have quite a widespread distribution in the southern half of the South Island in association with *Danthonia rigida*. A description of the grassland association of which *F. matthewsii* is an important part is being prepared.

Festuca novae-zelandiae is an outcrossing species (Connor and Cook, 1955), and judging from trials conducted to test the breeding system of *F. matthewsii*, it is also an outcrosser.

MATERIALS

Seed was collected in the field from the sites listed in Table 1 and illustrated in Fig. 1. All seed collections were sown in seed trays and after pricking out were planted in the experimental garden at 3 ft spacing. In most cases 100 plants per collection were grown. Also available were some plants transferred from the wild.

METHODS

The plants were one year old, growing vigorously and had not flowered at the time of sampling. Hackel recommended that for comparison with his results all sections should be cut from plants at flowering, but it would have been impossible for the author to have made this study at a time when the plants were in flower.

TABLE 1—Collection Data for *F. novae-zelandiae* and *F. matthewsii*

Festuca novae-zelandiae

Collection No.	Locality and Altitude
1.	North Dean, Waipara, North Canterbury, *ca* 1,000 ft.
2.	Craigieburn, inland Canterbury, *ca* 1,800 ft.
3	Porters Pass, inland Canterbury, 3,100 ft.
4.	Tweed side of Carters Saddle, Marlborough, 3,900 ft.
5.	"Tara Hills", Omarama, North Otago, 1,600 ft.
8.	"Eudunda", Culverden, North Canterbury, 1,500 ft.
9.	"Birch Toppings", Waiau, North Canterbury, 1,550–1,650 ft.
14.	"Mason Hills", Waiau, North Canterbury, 1,400–2,000 ft.
15.	Conway River, North Canterbury - Marlborough, 1,500 ft.
17.	Mt. Lyndon, inland Canterbury, 3,600 ft.
18.	Mt Lyndon, inland Canterbury, 2,700–3,200 ft.
19.	"Fagan Downs", Ashburton Gorge, 2,300 ft.
20.	Mt Harper, Ashburton Gorge aspect, 3,500–4,650 ft.
21.	Mt Harper, Ashburton Gorge aspect, 2,200–3,200 ft.
22.	"Clent Hills", Ashburton Gorge, 2,000 ft.
23.	Lake Heron, Ashburton Gorge, 2,200 ft.
24.	Ealing, South Canterbury, 400 ft.
25.	"Mt Peel Station", South Canterbury, 1,000 ft.
26.	Rawles Gully, South Canterbury, 1,500 ft.
27.	Rollesby Valley, South Canterbury, 1,500 ft.
28.	Mackenzie Pass, South Canterbury, 2,600 ft.
29.	Snow River, Mackenzie Country, South Canterbury, 2,000 ft.
30.	"Mt Hay", Mackenzie Country, South Canterbury, 2,700 ft.
31.	"Mt Hay", Mackenzie County, South Canterbury, 3,600 ft.
32.	"Mt Hay", Mackenzie Country, South Canterbury, 4,000 ft.
33.	Claycliff, Mt Mary Range, Mackenzie County, South Canterbury, 3,800 ft.
34.	Claycliff Stream, Mt Mary Range, Mackenzie Country, South Canterbury, 3,500 ft.
35.	Maryburn Hut, Mt Mary Range, Mackenzie Country, South Canterbury, 2,600 ft.
36.	Claycliff-Maryburn Catchment, Mt Mary Range, Mackenzie Country, South Canterbury, 4,050 ft.
37.	"Pukaki Downs", Mackenzie Country, South Canterbury, *ca* 2,000 ft.
39.	Hakataramea Pass, South Canterbury, 3,100 ft.
40.	Dalgety Stream, South Canterbury, 2,500 ft.
41.	"Round Hill", Hakataramea Valley, South Canterbury, 1,900 ft.
42.	Meyers Pass, Hakataramea Valley, South Canterbury, 2,050 ft.
43.	West Branch Awakino Riv., North Otago, 2,650–2,750 ft.
44.	West Branch Awakino Riv., North Otago, 2,250–2,650 ft.
46	West Branch Awakino Riv., North Otago, 1,000 ft.
47.	Thompson Creek, Dansey Pass Rd., North Otago, 1,300 ft.
48.	"Mt Alexander", Dansey Pass Rd., North Otago, 1,300 ft.
49	Bottom of Dansey Pass, North Otago, 2,100 ft.
50.	Dansey Pass, North Otago, 3,100 ft.
51.	Dansey Pass, Naseby side, North Otago, 2,500 ft.
52.	Dansey Pass, Naseby side, North Otago, 2,100 ft.
53.	Blackstone Hill, Central Otago, 1,600 ft.
54.	Manuherikia River near St Bathans, Central Otago, 1,850 ft.
55.	St Bathans, Central Otago, 1,900 ft.
56.	Kyeburn, Central Otago, 1,350 ft.
57.	Ranfurly, Central Otago, 1,500 ft.
58.	Shag River Bridge, North Otago, 1,850 ft.
59.	Pigroot, North Otago, 1,550 ft.
60.	Pigroot, North Otago, 2,000 ft.
61.	Burkes Pass, Mackenzie Country, South Canterbury, 2,200 ft.
70.	Lindis Pass, North Otago, 3,350 ft.
71.	Lindis Pass, North Otago, 3,350 ft.

Festuca matthewsii

A.	Handyside Creek, Waiau Riv. Catchment, North Canterbury, 3,300 ft.
B.	Handyside Creek, Waiau Riv. Catchment, North Canterbury, 3,300 ft.
C.	Handyside Creek, Waiau Riv. Catchment, North Canterbury, 2,900–3,100 ft.

Collection No.	Locality and Altitude
D.	Handyside Creek, Waiau Riv. Catchment, North Canterbury, 2,500–2,800 ft.
E.	West Branch Awakino Riv., North Otago, 2,650–2,750 cf. F. n–z43.
F.	West Branch, Awakino Riv., North Otago, 2,250–2,650 cf. F. n–z44.
G.	West Branch Awakino Riv., North Otago, 2,400 ft.
H.	Kirkliston Creek, Kirkliston Range, South Canterbury, 3,100–3,300 ft.
I.	Ohau Range, inland South Canterbury, 3,700 ft.
J.	"Ben Avon", Ahuriri Riv., North Otago, 3,000 ft.
K.	Ahuriri Riv., North Otago, 3,500 ft.
L.	Lindis Pass, North Otago, 3,300–3,600 ft.
M.	Crown Peak, Central Otago, 4,000–4,900 ft.
N.	Lindis Pass, North Otago, 3,300 ft.
O.	Benmore Range, North Otago, 2,500 ft.
P.	Benmore Range, North Otago, 1,600 ft.
Q.	Twizel Riv., South Canterbury, 2,900 ft.
R.	West Eweburn Dam, near Naseby, Central Otago, 2,500 ft.

F. novae-zelandiae 4 was collected by Miss L. B. Moore and *F. novae-zelandiae* 5 by Mr G. A. Dunbar.

FIG. 1—Map of South Island showing seed collection localities for *Festuca novae-zelandiae* and *F. matthewsii*.

Ten plants were sampled at random from each collection and one leaf per plant was sectioned. All sections were cut at the mid-point of the blade of the penultimate leaf of an innovation shoot. This is the leaf used by Hackel and in footnote 2 page 81 he states clearly thus "Ad describendam structuram histologicam foliorum comparandi causa semper innovationis folium summo proximum electum est". The mid-point on the blade is that designated clearly by St Yves (1927), and it also permitted direct comparison with the sections available on herbarium sheets in the Botany Division Herbarium. Burr and Turner (1933) recommend that the section should be cut from the upper part of the lower third of the blade of young vegetative leaves but offer no explanation for their choice of position nor are they careful as to what leaf is used. Hackel (*op. cit.*) does not indicate where in the lamina the section is cut. Howarth (1918) sectioned leaves about one-third the distance from the ligule.

Several transverse sections from each leaf were examined and a camera lucida drawing of one of them was made on a 5 in. × 3 in. punch card. Some sections are reproduced in Fig. 2.

The following characters were considered and coded on to the punch cards.

1. *Leaf shape.* Two classes
   (a) predominantly circular in outline
   (b) predominantly hexagonal in outline
2. *Number of vascular bundles.*
3. *Number of ridges.* The number of ridges depends on the number of furrows developed in the blade. Two furrows result in one ridge, three furrows in two ridges, four furrows in three ridges.
4. *Subepidermal sclerenchyma.* Four groups were recognised
   (a) Abaxial sclerenchyma arranged in 7 classes and 36 patterns.
   (b) Costal sclerenchyma*. Presence and position, 5 classes.
   (c) Supra-fascicular sclerenchyma. Presence or absence.
   (d) Attachment of vascular bundles to abaxial sclerenchyma. Presence or absence.

Of these four categories 4 a, b, c, and d, require more detailed amplification.

4. (a) *Abaxial Subepidermal sclerenchyma.* The arrangement and distribution of abaxial sclerenchyma is very variable, ranging from a continuous band or ring to many isolated groups of sclerenchyma. The simplest and most logical presentation of the arrangement of sclerenchyma is to relate it to the vascular bundles and marginal strands, as has been done by previous authors. As an early examination of the data from the sections revealed that 91% of *F. novae-zelandiae* and 80% of *F. matthewsii* sections had five vascular bundles, chief consideration was given to this five-vascular-bundle group. Five vascular bundles are also convenient, as symmetry is easily seen, and there are also fewer patterns than in six or seven vascular bundle groups.

*Sclerenchyma in the ridges and therefore adaxial.

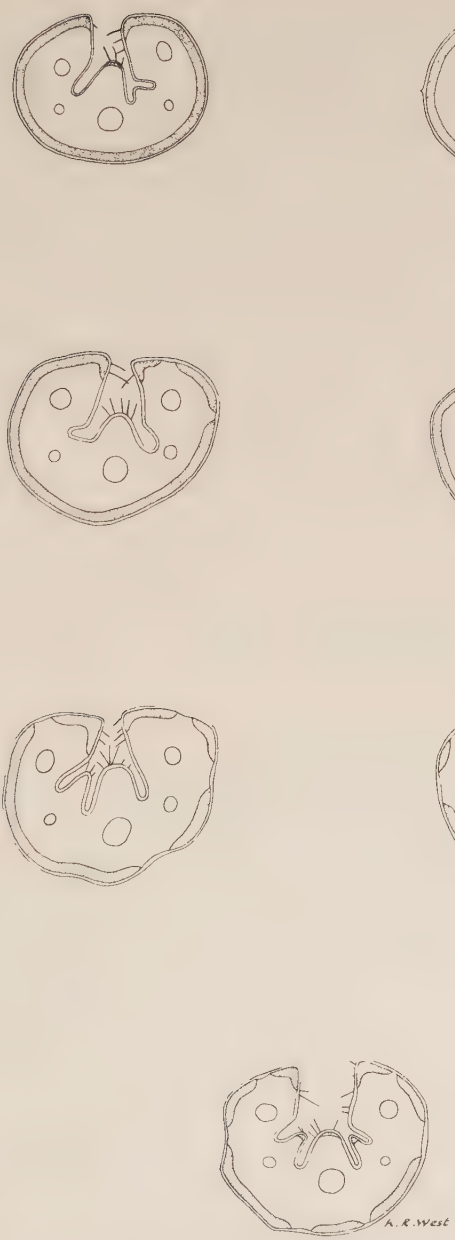

FIG. 2—Leaf sections in *Festuca novae-zelandiae* showing variation in subepidermal sclerenchyma (stippled), number of ridges, and costal sclerenchyma (stippled). One leaf from each subepidermal sclerenchyma class is illustrated, see also Fig. 3.

The several hundred five-vascular-bundle cards were sorted into seven classes with thirty-six patterns of sclerenchyma arrangement. After the thirty-six patterns had been recognised from the samples it was found that these thirty-six patterns in fact fitted all the possible theoretical patterns. The sclerenchyma classes were classified:

Class 0. No break in sclerenchyma (a continuous band) *1 pattern.*

Class 1. One break in sclerenchyma. This one break may be seen in any of six different places but as three are mirror images of the others there are *3 possible patterns.*

Class 2. Two breaks in sclerenchyma. These breaks may be seen in leaf section in fifteen possible pair combinations, but allowing for symmetrical arrangements and mirror images there are *9 possible patterns.*

Class 3. Three breaks in sclerenchyma. These may be seen in section in twenty apparent ways but half are mirror images. *10 possible patterns.*

Class 4. Four breaks in sclerenchyma. *9 possible patterns.*

Class 5. Five breaks in sclerenchyma. *3 possible patterns.*

Class 6. Six breaks in sclerenchyma. *1 pattern.*

The thirty-six patterns each with its code number, and arranged in seven classes, are illustrated in Fig. 3. In Class 6 each of the five vascular bundles is subtended by a strand of sclerenchyma and there are two marginal strands, making seven strands of sclerenchyma and six main breaks; at the other extreme, Class 0, the subtending strands and the marginal ones are united into a continuous band. Classes 1 to 5 show the range of conditions between Classes 0 and 6.

The series of lines connecting patterns show the relationship between patterns and classes based on a fusion of any two sclerenchyma strands (thus reducing the number of breaks) assuming that fusions occur one at a time. In the example illustrated by the radiating lines in Fig. 3, a fusion of any two sclerenchyma strands in pattern 6·1 leads to patterns 5·1, 5·2, and 5·3. A fusion of any two sclerenchyma strands in pattern 5·2 can only lead to patterns 4·3, 4·5, 4·6, 4·8 and 4·9. Similarly a single fusion in pattern 4·5 leads only to patterns 3·1, 3·3, 3·4, and 3·7. All patterns can be followed through in the way outlined in the example. Symmetrical patterns, however, always lead to fewer patterns than asymmetrical ones, e.g. pattern 4·7 following the fusion of any two strands of sclerenchyma leads only to patterns 3·6 and 3·10. Though a single fusion of strands may, as in the case of pattern 5·2, lead to 5 possible patterns, it never leads to patterns in all three groups A, B, and C.

While the sequence of sclerenchyma fusions within a leaf may not be expected to occur one at a time and to follow the scheme outlined in Fig. 3, *F. novae-zelandiae* 5 (1H) detailed in Table 3 shows that, within the limitations of the sampling method, such a sequence did in fact occur, although in all other leaves examined it did not.

The arrangement of patterns in a class is not altogether arbitrary. Once patterns 5·1, 5·2, 5·3 were arbitrarily fixed, then there is an intentional and logical grouping of patterns in a class, based on the condition of the marginal

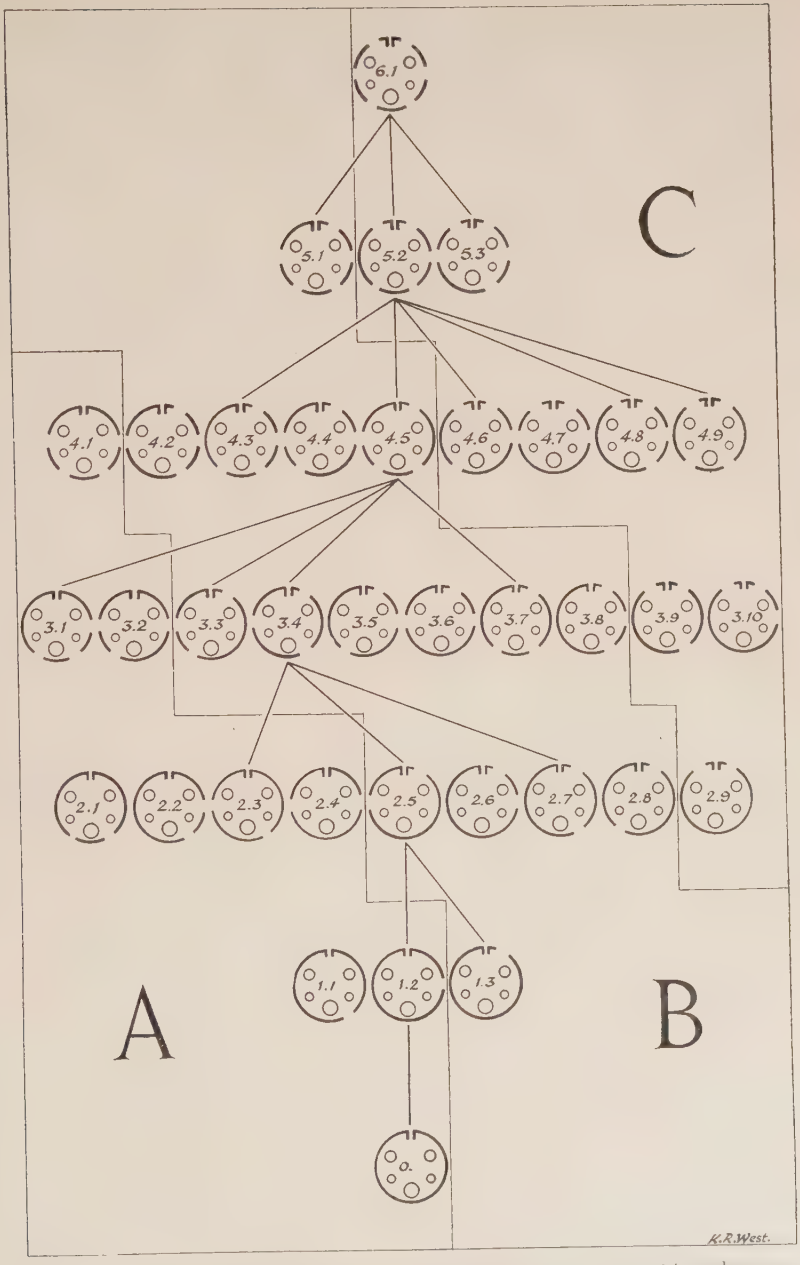

FIG. 3—Diagram of subepidermal sclerenchyma patterns, each with code number, arranged in seven classes. Sclerenchyma and vascular bundles only are illustrated. Radiating lines connecting patterns show interrelation. Fuller explanation in text.

sclerenchyma strands. This grouping which is not entirely artificial, is outlined in Table 2, and illustrated in Fig. 3.

Group A has two marginal strands united with nearest subtending sclerenchyma.

Group B has one marginal strand united with nearest subtending sclerenchyma.

Group C has two marginal strands free.

TABLE 2—Distribution of Patterns of Abaxial Subepidermal Sclerenchyma in Groups

Class	Group A	Group B	Group C
0	0		
1	1.1, 1.2	1.3	
2	2.1, 2.2, 2.3, 2.4	2.5, 2.6, 2.7, 2.8	2.9
3	3.1, 3.2	3.3, 3.4, 3.5, 3.6, 3.7, 3.8	3.9, 3.10
4	4.1	4.2, 4.3, 4.4, 4.5	4.6, 4.7, 4.8 4.9
5		5.1	5.2, 5.3
6			6.1
Total	10	16	10

Where additional strands of sclerenchyma are present between any two strands subtending vascular bundles, these do not upset pattern classification. Addition of another point and an indication of the number of additional strands leaves the system of coding flexible. For example, in pattern 6.1, there are seven main strands of sclerenchyma, but there may be four additional strands distributed between the subtending strands. The coding for this section is then 6.1.4.

This system of recording patterns can quite easily be extended to leaves with more than five vascular bundles, but it was not considered necessary for this particular set of data.

4(b) *Costal sclerenchyma* may be present or absent in the ridges on the adaxial surface of the leaf. Scoring allowed for presence or absence, and, if present, for position. Presence in median ridge only, median and one lateral ridge, median and two lateral ridges, or lateral ridge(s) only, was recognised.

4 (c) *Supra-fascicular sclerenchyma* is here regarded as that adaxial sclerenchyma developed above the uppermost pair of vascular bundles where ridges are not clearly developed. Supra-fascicular adaxial sclerenchyma strands eventually fuse with the marginal strands towards the base of the leaf and the marginal strands become very long. Towards the base of the leaf there is sometimes an almost complete union of abaxial and adaxial subepidermal sclerenchyma.

4 (d) *Vascular bundles* are in some instances joined (by a group of sclerenchyma cells) to the abaxial subepidermal sclerenchyma. In the species studied here there is never the formation of the I-shaped girder (the "doble T" of Parodi), but only half I-girders, cf. Fig. 6.

PATTERNS OF DEVELOPMENT IN LEAF BLADES

Although the initial aim was to record the variation in leaf anatomy and to endeavour to relate it to the taxonomic use of this character, it was deemed wise to investigate the patterns at various levels in single leaves. Penultimate leaves from innovation shoots were examined in 13 plants of *Festuca novae-zelandiae* and 3 plants of *F. matthewsii.*

Individual leaves were sectioned close to the ligule, at ½ in. above the ligule and at 1 in. intervals to the apex, and drawn in the manner described above. Table 3 shows the condition of each section at each sampling point for six characters: (1) abaxial subepidermal sclerenchyma pattern; (2) number of vascular bundles; (3) number of ridges; (4) presence of costal sclerenchyma; (5) attachment of vascular bundles to abaxial sclerenchyma; (6) presence of supra-fascicular sclerenchyma. Asterisks mark the sections likely to have been cut at the usual sampling point. One section in *F. novae-zelandiae* 19 was lost and a series of values marked † are interpolated for it.

The collections of *F. novae-zelandiae* were 2, Craigieburn; 3, Porters Pass; 5, "Tara Hills"; 19, "Fagan Downs"; G.454, Kaimanawa Mts; and G. 869, 870 from Mt Lyndon, and G. 875 from Mt Harper, which all belong to a recognisable high altitude race. *F. matthewsii* I from Ohau Range was used.

From the evident changes within a leaf seven trends are visible in *F. novae-zelandiae.*

(i) Abaxial sclerenchyma pattern is most commonly 6.1 at the apex, G. 869 and G. 870 are exceptions.

(ii) A tendency to fusion of the originally separate strands of sclerenchyma from apex to base.

(iii) An increase in the number of vascular bundles from the apex towards the base.

(iv) An increase in the number of ridges from the apex towards the base.

(v) A reduction in the presence of costal sclerenchyma from base to apex.

(vi) A reduction in the frequency of the attachment of vascular bundles to abaxial sclerenchyma from base to apex.

(vii) A reduction in the presence of supra-fascicular sclerenchyma from base to apex.

The six histological gradients are illustrated diagrammatically in Fig. 1.

TABLE 3—Within Leaf Variation in Samples Made From Tip to Base of Blade in *F. novae-zelandiae* and *F. matthewsii*

Column 1. Abaxial sclerenchyma pattern code
2. Number of vascular bundles
3. Number of ridges
4. Costal sclerenchyma
5. Attachment of vascular bundles to abaxial sclerenchyma
6. Supra-fascicular sclerenchyma

* Normal sampling position P Present

Festuca novae-zelandiae

Inches From Base of Leaf	5 (3N)						5 (1H)						5 (7M)						5 (11A1)						G454						3 (2)						2 (6)					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
12½	6·1	5	1				6·1	5	1				6·1	4	1				6·1	5	1				6·1	5	1															
11½	6·1	5	1				6·1	5	1				6·1	5	1				6·1	5	1				6·1	5	2															
10½	6·1	5	1				6·1	5	1				6·1	5	1				6·1	5	1				6·1	5	3															
9½	6·1	5	1				6·1	5	2				6·1·1	5	1				5·1	5	1				6·1	5	3				6·1	3	1				6·1	5	1			
8½	5·1	5	1				5·3	5	2				6·1·1	5	2				6·1	5	1				6·1	5	3				5·1	5	1				4·6	5	2			
7½	6·1	5	1				5·3	5	2				6·1	6	3				6·1	5	1				6·1	5	3		P		6·1	4	1				1·1	5	3			
6½	6·1·1*	5	1				5·3*	5	2				6·1·2*	6	3				5·3*	5	1				6·1*	5	3	P	P		5·3	4	1				0	5	3			
5½	6·1	5	1				5·3·1	5	2				6·1	6	3				5·3	5	1				6·1	5	3	P			5·1	5	1	P			0	5	3			
4½	6·1	5	1				4·2·1	5	2	P			6·1	5	3				6·1	5	1				6·1	5	3	P		P	3·1*	5	1	P			0*	5	3			
3½	6·1	5	1	P			3·6	5	2	P			5·3·1	7	3				5·3	5	1				5·2	5	2	P		P	4·1	5	1	P			0	5	3			
2½	6·1	5	1				2·6	5	2	P			5·3	8	3				6·1	5	1				6·1	5	2	P		P	5·1	5	1	P			0	5	3	P		
1½	3·2	5	1	P	P		1·2	5	2	P			4·8	8	3		P		4·7	5	1	P			4·1	5	2	P		P	5·1	5	1	P			0	5	3	P	P	
½	2·4	5	1	P	P		0	5	2	P	P	P	1·2	8	3		P		2·4	5	1		P		3·2	5	2	P	P	P	4·1	5	1	P			0	5	3	P	P	P
0	0	5	1	P	P		0	5	2	P	P	P	0	7	3	P	P	P	0	5	1	P	P		0	5	2	P	P	P	3·1	5	1	P	P		0	5	3	P	P	P

Festuca novae-zelandiae

Inches From Base of Leaf	19 (97)						G875 (2)						G875 (1)						5 (11A2)						G869						G870					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
12½																									0	5	1	P								
11½																									0	5	3	P								
10½																									0	5	3	P			0	5	1	P		
9½																									0	5	3	P			0	5	3	P		
8½	6·1	4	1																						0	5	3	P			0	5	3	P		
7½	5·1	5	1				6·1	5	1																0	7	3	P			0	5	3	P	P	P
6½	5·1	5	1	P			5·2	5	1				5·1	5	2										0*	7	3	P	P		0	6	3	P	P	P
5½	6·1	5	2	P			4·3	5	2	P			3·5	5	3	P			6·1	4	1				0	7	3	P	P		0*	6	3	P	P	P
4½	6·1*	5	2	P			1·1*	5	3	P			0*	5	3	P			6·1	5	1				0	7	3	P	P		0	5	3	P	P	P
3½	6·1†	5	2	P			2·2	5	3	P			0	5	3	P			6·1*	5	1				0	7	3	P	P	P	0	6	3	P	P	P
2½	5·1	5	2	P			1·1	5	2	P			0	5	3	P			6·1	5	1				0	7	3	P	P	P	0	6	3	P	P	P
1½	4·3	5	2	P			1·1	5	1	P		P	1·3	5	3	P		P	6·1	5	1				0	7	3	P	P	P	0	6	3	P	P	P
½	2·1	5	2	P			0	5	1	P	P	P	0	5	3	P		P	6·1	5	1				0	7	3	P	P	P	0	6	3	P	P	P
0	0	5	2	P			0	5	1	P	P	P	0	5	3	P	P	P	2·4	5	1				0	7	3	P	P	P	0	6	3	P	P	P

†Interpolated.

TABLE 3 (*continued*)—Within Leaf Variation in Samples Made From Tip to Base of Blade in *F. novae-zelandiae* and *F. matthewsii*

Column 1. Abaxial sclerenchyma pattern code
2. Number of vascular bundles
3. Number of ridges
4. Costal sclerenchyma
5. Attachment of vascular bundles to abaxial sclerenchyma
6. Supra-fascicular sclerenchyma

* Normal sampling position P. Present

F. matthewsii

Inches From Base of Leaf	I (59)						I (60)						I (80)					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
12½	6·1	5	1				6·1	5	3		P							
11½	6·1	5	3				6·1·1	5	3		P							
10½	6·1·2	5	3				6·1·3	5	3									
9½	6·1·2	5	3		P		6·1·2	6	3									
8½	6·1·2	5	3				6·1·3	6	3		P							
7½	6·1·3	5	3				6·1·3	6	3									
6½	*5·1·2	5	3		P		*6·1·3	6	3		P		6·1·2	5	3			
5½	5·1·1	5	3				6·1·3	6	3		P		6·1·3	5	3	P		
4½	6·1·1	5	3		P		6·1·3	6	3		P		6·1·2	5	3			
3½	5·1	5	3		P		6·1·3	6	3		P		*6·1·2	5	3	P		P
2½	1·1	5	3		P		6·1·2	6	3	P	P	P	6·1·1	5	3	P		P
1½	1·1	5	3		P		6·1·1	6	3	P	P	P	6·1·1	5	3	P	P	P
½	1·1	5	3		P		4·1	6	3	P	P	P	6·1·1	5	3	P	P	P
1/16	0	5	3	P	P		0	6	3	P	P	P	5·1	5	3	P	P	

In Fig. 5 four abaxial sclerenchyma patterns are illustrated and show some of the changes that occur within the leaf blade. Figure 6 is a skeletal drawing, showing, in particular, the development of ridges and costal and supra-fascicular sclerenchyma.

Although the sample is small *F. matthewsii* shows some similar trends, but the number of ridges stabilises sooner and the attachment of vascular bundles to abaxial sclerenchyma appears more marked, as also is the supra-fascicular sclerenchyma. Most striking of all is the tendency, after the early definition of 6.1 pattern, to the formation of additional strands of abaxial sclerenchyma, almost to the point where there is an extra strand to each vascular bundle (cf. section on additional strands, p. 492). The tendency to fusion of abaxial sclerenchyma strands is not as marked as in *F. novae-zelandiae* and though this fusion does occur it takes place lower down in the leaf than in *F. novae-zelandiae*.

Using the information in Table 3 and the above trends, data from a single section can be used to predict the condition of the leaf towards the apex and the base.

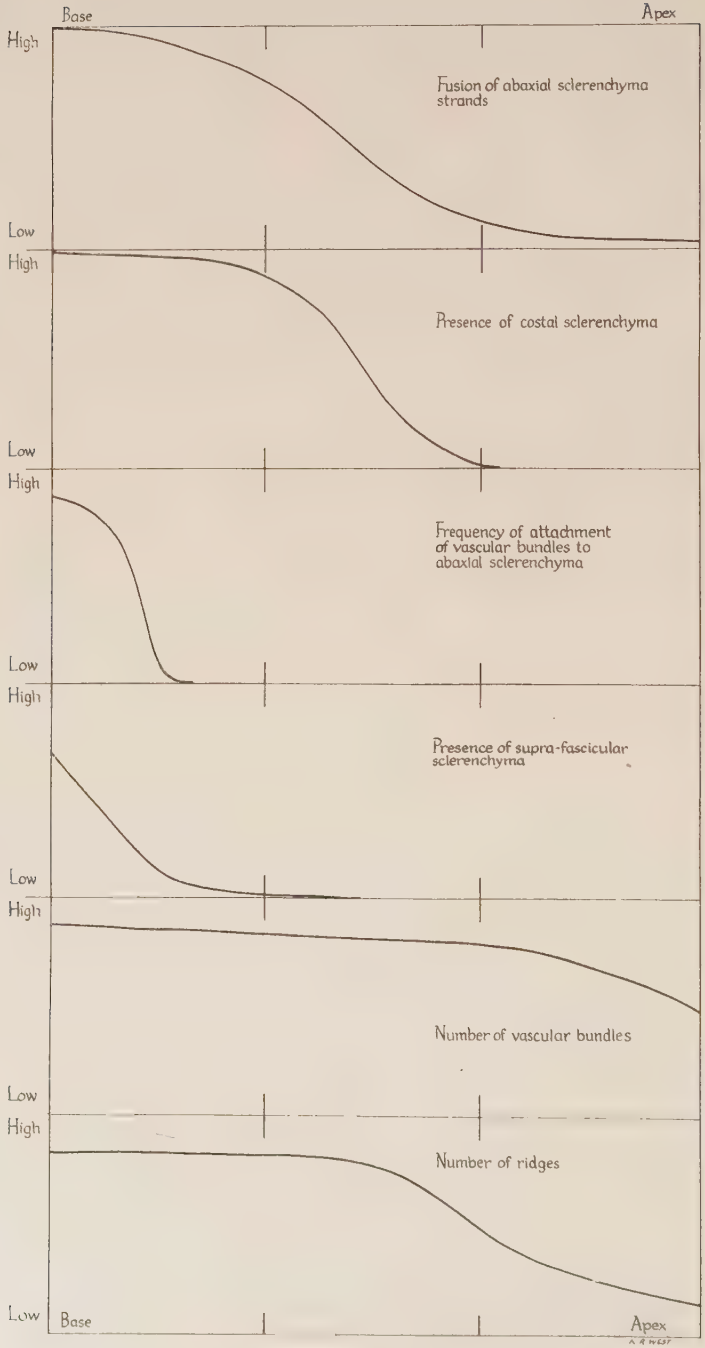

FIG. 4—Six histological gradients in leaves of *Festuca novae-zelandiae*.

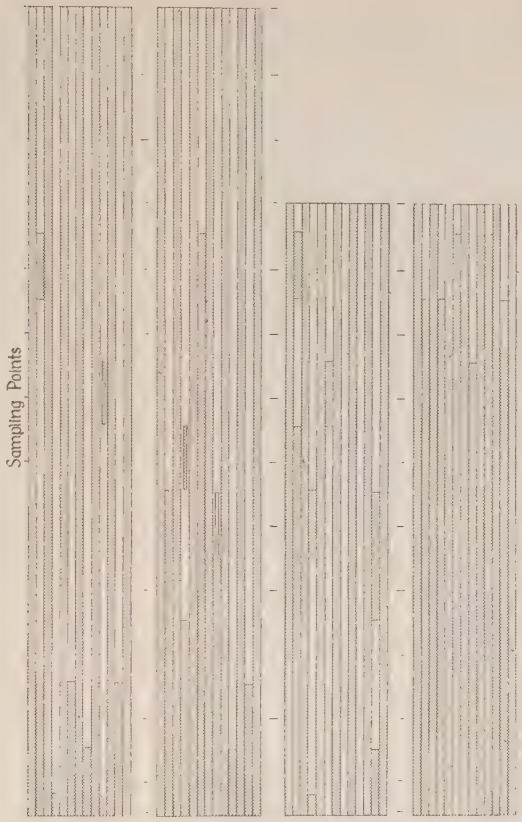

FIG. 5—Diagram of abaxial subepidermal sclerenchyma (stippled) from apex to base in four leaves of *Festuca novae-zelandiae*, constructed from sections made at sampling points. For convenience the leaves are shown flattened out. Left to right *F. novae-zelandiae* 5(3N); 5(1H); 3(2); 2(6). See also Table 3.

WITHIN PLANT VARIATION

Apart from the between plant and the within and between population variation which was a main purpose of the study, some time was directed to within-plant variation.

One plant of *F. novae-zelandiae* 19 was sampled more intensively than others. Three shoots were selected, viz.

Shoot 1. 4 leaves, no tillers.

Shoot 2. 5 leaves, and the leaf of one tiller emerged.

Shoot 3. 6 leaves, and three tillers developed.

All leaves were sampled at the mid-point. All the leaves on a plant are potential sample leaves at some stage in time though at the precise time of sampling any of the 5 penultimate leaves on the three shoots could have

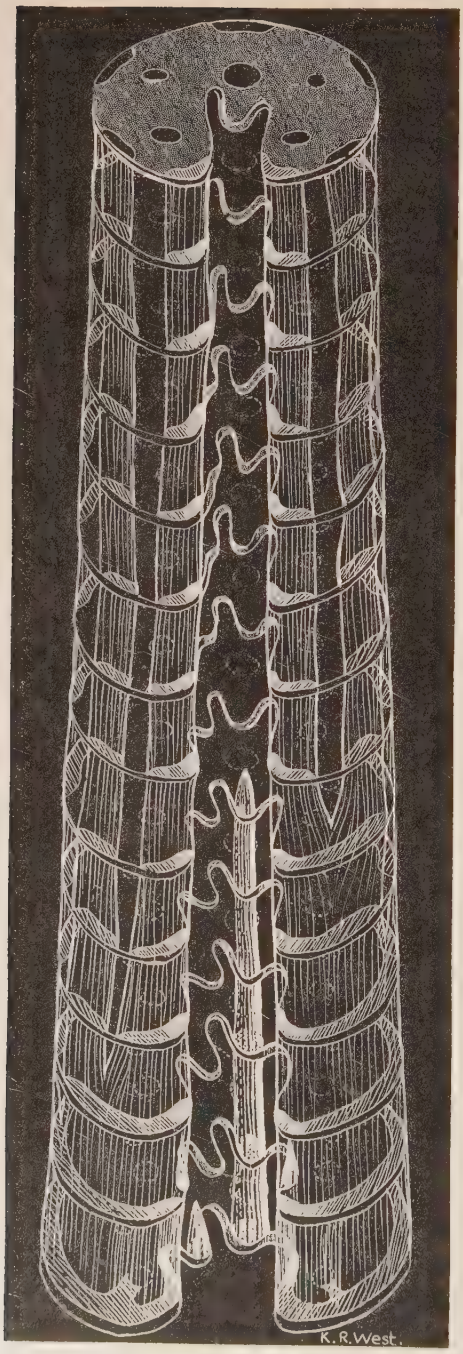

FIG. 6—Skeletal diagram of a leaf of *F. novae-zelandiae* 5 (1H) constructed from sections at sampling points, viewed from the front showing number of ridges, and development of costal and supra-fascicular sclerenchyma. The vertical interval between the lowest two sampling points is slightly exaggerated.

been finally sampled. In Table 4 abaxial sclerenchyma pattern, number of ridges, and the presence and position of costal sclerenchyma is indicated. All samples had 5 vascular bundles.

The results indicate that the sample leaf could have been any of 5 different values depending on the one finally sampled. The within-plant variation is high, but of the 22 leaves, 7 are of one value, 3 of another, 2 of a third, leaving 10 leaves all of differing values.

TABLE 4—Within Plant Variation for 3 Characters in *F. novae-zelandiae* 19, Plant 97

Shoot No.	Leaf Number					
	1†	2	3	4	5	6
	1	1	1	1	1	1
1	3.1 3 M	3.1 2 M+1L	2.2* 3 M+2L	2.1 3 M+2L		
2	6.1 1 A	6.1 1 A	6.1 1 M	4.1* 2 M	6.1 3 M+1L	
3	6.1 1 A	6.1 1 M	6.1 2 M	5.1 2 M+1L	4.9* 3 M	4.3 2 M

Shoot No.	Leaf Number					
	1	2	3	1	2	1
	1.2	1.2	1.2	1.3	1.3	1.4
2				6.1 1 A		
3	6.1 1 A	6.1* 1 M	6.1 2 M	6.1* 1 A	5.1 1 A	6.1 1 A

*Penultimate leaf.

†Leaf and tiller notations after Percival (1921).

1st Line. Abaxial sclerenchyma pattern.

2nd Line. Number of ridges.

3rd Line. Costal sclerenchyma. A absent, M present in median ridge; M+1L present in median and lateral ridge; M+2L present in median and 2 lateral ridges.

There is perhaps a suggestion that in each shoot there is a tendency towards more sclerenchyma, either in reduced number of breaks or in presence of costal sclerenchyma as the leaves occur higher up the stem.

Whilst it is possible to draw some conclusions about an individual leaf from its sample it seems difficult to draw conclusions about the plant from which the sample was taken. A further plant, No. 16 of *F. novae-zelandiae* 9, was examined in less detail than Coll. 19. The results are presented in Table 5. In this plant the penultimate leaf showed most of its variation in the abaxial sclerenchyma.

TABLE 5—Within Plant Variation *F. novae-zelandiae* 9, Plant 16

Shoot No.	Leaf		
	Ante-penultimate	Penultimate	Ultimate
1	.....	2.5 1 A 5	
2	.....	6.1 1 A 5	3.1 2 A 5
3	4.7 2 A 5	3.2 1 A 5	0 3 A 6
4	1.2 3 A 7	2.3 2 A 6	

Line 4. Number of vascular bundles, otherwise as for Table 4.

In *F. novae-zelandiae* 5 a pair of samples from plant 11A were identical, but this pair which probably told a lot about the plant in fact told little about the population (cf. Table 12).

The problem of relating the sample to the plant and then the plant to the population as a whole becomes increasingly difficult. Coll. 19 plant 97 showed more intraplant variation than did the 8 samples from the whole population listed in Table 12, while *F. novae-zelandiae* 5 (11A) revealed patterns of abaxial sclerenchyma not met with in the 7 samples in Table 12.

POPULATION ANALYSIS

Collections of *F. novae-zelandiae* growing in the experimental gardens at Lincoln were sampled, and drawings were available for comparison with specimens in the Botany Division Herbarium. These constitute the available samples and will be considered under the two separate headings of "Garden grown plants" and "Herbarium Specimens".

Garden Grown Plants

LEAF SHAPE

Leaf shape for the greater part was either circular or hexagonal and in those cases where difficulties arose leaves were classified as predominantly circular or hexagonal as they tended to be in either of the two classes.

The frequencies of circular and hexagonal leaves in both species are given in Table 6.

TABLE 6—Leaf Shape Frequencies in *F. novae-zelandiae* and *F. matthewsii*

Species	Circular	Hexagonal	Total	No. of Collections
F. novae-zelandiae	409(82·5%)	87(17·5%)	496	54
F. matthewsii	83(78·3%)	23(21·7%)	106	18

In a test of heterogeneity for leaf shape $\chi_1^2 = 1{\cdot}011$ and gave a probability of approximately 0·30. The proportions of circular and hexagonal in both species are very similar.

In 16 of the 54 collections of *F. novae-zelandiae*, all leaves were circular, and in 38 collections there were mixtures of circular and hexagonal sections. No particular association of leaf shape and eco-geographic grouping of collections is evident, nor is there any particular trend when comparison is made in *F. matthewsii* between plants from areas free from *F. novae-zelandiae* and areas where the species are sympatric.

Leafshape of itself is not a very useful diagnostic character. Hackel (1903) and Howarth (1928) and St Yves (1931) agree that in *F. novae-zelandiae* the leaves in section are cylindrical, and that in *F. matthewsii* the leaf section is obtusely hexagonal. The evidence presented in the present paper is not in perfect agreement.

The shape of leaves is governed to a great extent by the disposition of abaxial sclerenchyma. A leaf with a continuous band of sclerenchyma is never hexagonal, and the general tendency is for all hexagonal leaves to be abaxial sclerenchyma pattern 6·1 (5 of the 87 hexagonal leaves in *F. novae-zelandiae* were not pattern 6·1, and in *F. matthewsii* 3 of the 23 hexagonal leaves were not in pattern 6·1).

NUMBER OF VASCULAR BUNDLES

The number of vascular bundles is easily counted in a section. The number of bundles varied in *F. novae-zelandiae* from 4 to 9 and in *F. matthewsii* from 5 to 10. The frequencies for the number of vascular bundles are given in Table 7.

The most frequent vascular bundle number is 5 and accounts for just more than 90% of the *F. novae-zelandiae* samples and 80% of *F. matthewsii*. The species are significantly heterogeneous ($P. < {\cdot}001$) for frequencies of the number of vascular bundles. It has been shown earlier in Table 3 that the number of vascular bundles increases from the apex but that at the

sampling point the number is usually stable, although there is no particular position in the blade where the number increases. *F. matthewsii* has usually more vascular bundles than *F. novae-zelandiae*.

TABLE 7—Frequencies of Vascular Bundle Number in *F. novae-zelandiae* and *F. matthewsii*

No. of Vascular Bundles	*F. novae-zelandiae*	*F. matthewsii*
4	1 (0.2%)	0
5	452 (91.1%)	85 (80.2%)
6	26 (5.2%)	9 (8.5%)
7	12 (2.4%)	5 (4.7%)
8	3 (0.6%)	5 (4.7%)
9	2 (0.4%)	1 (0.9%)
10	0	1 (0.9%)
Total	496	106

NUMBER OF RIDGES

The number of ridges in leaves was determined by reference to the number of furrows developed (see p. 472). A median ridge is always developed over the main vascular bundle and lateral ridges may or may not be developed over the two adjacent bundles. The frequencies for the number of ridges is given for both species in Table 8.

TABLE 8—Frequencies of Ridge Numbers in *F. novae-zelandiae* and *F. matthewsii*

No. of Ridges	*F. novae-zelandiae*	*F. matthewsii*
1	116 (23.4%)	1 (0.9%)
2	155 (31.2%)	8 (7.5%)
3	224 (45.2%)	93 (87.7%)
4	1 (0.2%)	2 (1.9%)
5	0	2 (1.9%)
Total	496	106

The number of ridges in *F. novae-zelandiae* varied from 1 to 4 and in F. *matthewsii* from 1 to 5. A heterogeneity test resulted in $\chi^2 = 85{\cdot}686$, $P < {\cdot}001$. *Festuca matthewsii* has more ridges than *F. novae-zelandiae* but the use of the number of ridges as a taxonomic character must be considered statistically.

Hackel (*op. cit.* p. 21) states that the number of ridges is a character of importance; but, in his descriptions of the New Zealand species, omits to give the ridge numbers. St Yves (1931, p. 296) states for *F. novae-zelandiae* α *genuina* "intus 1 vel irregulariter 2–3 costatae, costa media elevata", and in discussing Howarth's 1928 paper corrects Howarth (and they had both studied A. Wall's material) who had indicated that there was

only a median ridge. St Yves continues "le nombre des côtes ne parait pas dependre due ± grand diametre des limbes", with which the present author agrees. St Yves (1931) illustrates in Fig. 3 p. 299 3 ridges in *F. novae-zelandiae* var. *grandiflora,* and on p. 302 Fig. 4 shows 3 ridges in *F. matthewsii.*

Within the collections no particular pattern of ridges can be distinguished. In the 54 collections of *F. novae-zelandiae* 40 showed 1, 2, or 3 ridged leaves in each collection, 2 showed 3 ridged leaves only (9 plants in these 2 collections) while the remaining eleven collections were mixtures. In Coll. 9 a four-ridged leaf was recorded.

SUBEPIDERMAL SCLERENCHYMA

Subepidermal sclerenchyma has been discussed in an earlier section (p. 472) and the recognition of patterns for both adaxial and abaxial sclerenchyma outlined. Hackel (*op. cit.* p. 24) stated that the development and arrangement of sclerenchyma in the leaves offers a most important character for determining *Festuca* "Formen", and it is again appropriate to draw attention to Metcalfe's opinion (1955).

The ensuing discussion will be limited to the leaf sections in both species which had five vascular bundles of which there were 452 in *F. novae-zelandiae* and 85 in *F. matthewsii.* In those cases where the number of vascular bundles was greater than five the additional bundles were usually very small and occurred mostly in unbalanced ways. It has been calculated that if those samples had been included in the 5-vascular-bundle group there would be only small changes in the percentages in the class outlined below. As previously indicated subepidermal sclerenchyma is invariably present on the abaxial surface but may or may not be present on the adaxial one. This section will therefore be discussed under the two headings "Abaxial Sclerenchyma" and "Adaxial Sclerenchyma".

Abaxial Sclerenchyma

In Table 9 the frequencies in abaxial sclerenchyma classes for both species are indicated.

TABLE 9—Frequencies in Abaxial Sclerenchyma Classes for *F. novae-zelandiae* and *F. matthewsii*

Class	Possible Patterns	*F. novae-zelandiae*		*F. matthewsii*	
		Frequency	No. Patterns Recorded	Frequency	No. Patterns Recorded
0	1	41 (9.1%)	1	6 (7.1%)	1
1	3	17 (3.8%)	3	2 (2.4%)	2
2	9	27 (5.9%)	9	10 (11.8%)	5
3	10	28 (6.2%)	10	4 (4.7%)	4
4	9	41 (9.1%)	9	9 (10.6%)	3
5	3	56 (12.4%)	3	9 (10.6%)	3
6	1	242 (53.5%)	1	45 (52.9%)	1
Total	36	452	36	85	19

The distribution in the classes appears very much the same and a heterogeneity test gave $\chi^2 = 4{\cdot}603$ which with d.f. = 6, $\cdot 50 < P < \cdot 70$, a quite good fit.

The most evident feature from Table 9 is that for both species more than half the populations are in Class 6. Class 6 is represented in 52 of the 54 *F. novae-zelandiae* collections and in 14 of the 15 collections of *F. matthewsii*. In the two collections of *F. novae-zelandiae* where Class 6 was absent both were based on 3 samples instead of the desired 10, and in *F. matthewsii* F only 2 sections were available in the collection.

The frequency of occurrence in the thirty-six individual patterns is given in Table 10. Many patterns are represented by very low frequencies in *F. novae-zelandiae* and a great many are absent altogether in *F. matthewsii*. In *F. novae-zelandiae* frequencies greater than 1% occurred in patterns 0; 1·1, 1·3, 2·1, 2·5; 3·1, 3·6; 4·1, 4·5, 4·7; 5·1, 5·2; 6·1. These fourteen patterns account for 408 (90%) of the samples.

TABLE 10—Frequencies of Abaxial Sclerenchyma Patterns in *F. novae-zelandiae* and *F. matthewsii*

Pattern Code No.	*F. novae-zelandiae*	*F. matthewsii*	Pattern Code No.	*F. novae-zelandiae*	*F. matthewsii*	Pattern Code No.	*F. novae-zelandiae*	*F. matthewsii*
0	41	6	3·1	7	1	4·4	3	0
1·1	10	1	3·2	1	0	4·5	6	0
1·2	1	0	3·3	2	1	4·6	1	0
1·3	6	1	3·4	1	0	4·7	8*	3
2·1	8	3	3·5	1	1	4·8	3	0
2·2	2	0	3·6	7	0	4·9	4	4
2·3	1	1	3·7	1	1	5·1	10	1
2·4	1	0	3·8	1	0	5·2	26	4
2·5	7	0	3·9	3	0	5·3	20	4
2·6	4	0	3·10	4	0	6·1	242	45
2·7	1	1	4·1	10	0			
2·8	1	1	4·2	1	0			
2·9	2	4	4·3	5	2			

TOTALS: *F. novae-zelandiae* 452, *F. matthewsii* 85.
*Mostly contributed by a special collection of F. n–z 5.

While discussing the patterns with high frequencies in *F. novae-zelandiae* it is also appropriate to consider the highest frequencies in each class. In Class 0 and Class 6 there is only 1 pattern but among the remaining classes there are 34 patterns. The highest frequencies in each class are 0, 1·1, 2·1, 3·1, 4·1, 5·2, and 6·1. These patterns were not arranged so that the first pattern in each class had the highest frequency. Once the arrangement of 5·1, 5·2, and 5·3 were fixed the other patterns in the classes developed from these. The 14 patterns with high frequency were classified into three groups in the manner outlined in Table 2, based on the extent to which marginal

sclerenchyma strands are fused with the abaxial sclerenchyma which subtends the uppermost vascular bundles. This analysis is listed in Table 11 where the symmetrical patterns are indicated as well.

TABLE 11—Classification in Groups of *F. novae-zelandiae* High Frequency Patterns

Marginal Sclerenchyma Strands		
Both United to Nearest Sclerenchyma	One Strand Free	Two Strands Free
0*†	1.3	4.7†
1.1*	2.5	5.2*
2.1*†	3.6	5.3
3.1*	4.5	6.1*†
4.1*†	5.1	.....

*Highest frequency in class.
†Symmetrical arrangement of abaxial sclerenchyma.

Inspection of Table 11 shows that 5 of the "highest frequencies in a class" are in the group where there is fusion of the marginal strand sclerenchyma with those which subtend the uppermost vascular bundles. Patterns of high frequency are distributed evenly throughout the three groups and nothing significant can be inferred from this.

Symmetrically arranged abaxial sclerenchyma is present in 8 of the 36 patterns but it is here not interpreted as significant that 5 of them are in the high pattern frequency group.

There is one apparent developmental path associated with highest frequency patterns in classes which appears to be significant. This is in the group where both marginal strands are united to subtending abaxial sclerenchyma. An examination of the development of sclerenchyma in the series of sections made down leaf blades (cf. Table 3) shows that there is a strong tendency for the marginal strands to unite with those subtending the uppermost vascular bundles before there is a fusion of any of the other strands. These high frequency patterns in classes probably reflect a stage of development in the leaves.

Distribution of Patterns in Collections

In Table 12 the distribution of patterns with a frequency greater than 1% is detailed for 36 collections of *F. novae-zelandiae*. The collections are grouped eco-geographically so that some direct comparisons can be made. The most common feature of Table 12 is the presence in all but one collection, though in varying frequencies, of pattern 6·1. In Collection 42 from Meyers Pass all samples were 6·1, and in Collection 5 from Omarama no 6.1 pattern was recorded, although this collection when the sample size was increased beyond the standard 10 samples, included pattern 6·1. The high altitude collections 17, 20, 31, 33, 36, show fewer 6·1 patterns than do the lowland group but collection 31 from 3,600 ft at Mt Hay in the Mackenzie Country did not fit this trend. These five high altitude collections have 36% of their samples in 6·1 by comparison with 59% for the lower altitude ones.

TABLE 12—Thirty-six Collections of *Festuca novae-zelandiae* Showing Frequencies of Subepidermal Sclerenchyma Pattern in Each Collection

| Pattern Code | Collection Number | | |

TABLE 13—18 Collections of *F. matthewsii* Showing Frequencies of Abaxial Sclerenchyma Patterns in Each Collection

Pattern Code	Collection																				Total
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R			
0	1		1	2				1								1					6
1·1		1																			1
1·3						1															1
2·1		1	1	1																	3
2·3				1																	1
2·7	1																				1
2·8				1																	1
2·9	2							1									1				4
3·1			1																		1
3·3	1																				1
3·5								1													1
3·7	1																				1
4·3	1			1																	2
4·7								1					1		1						3
4·9				1				1				1			1						4
5·1				1																	1
5·2			1			1			1							1					4
5·3			1				1				1	1									4
6·1	3	2	3	2	3		3	2	6	2	1	3	4	2	1	3	3	2			45
Total	10	4	8	10	3	2	4	7	7	2	2	5	5	2	3	5	4	2			85

Discussion on intra- and inter-population variation for *F. novae-zelandiae* and *F. matthewsii* will be left till after the results from examination of herbarium specimens are detailed.

In *Festuca matthewsii* 18 collections were studied and the results are presented in Table 13. Again the most evident feature is the presence of pattern 6·1, present in all but one collection. All patterns present are recorded in this table.

Additional Strands of Abaxial Sclerenchyma

As has been indicated, apart from the sclerenchyma strands subtending the vascular bundles, additional and usually small strands occur from time to time between the main strands. The frequencies for additional strands and their distribution in the 7 classes of abaxial sclerenchyma are given in Table 14 for both taxa.

TABLE 14: Frequencies for Additional Sclerenchyma Strands in *F. novae-zelandiae* and *F. matthewsii* Classified in Abaxial Sclerenchyma Classes

Class	Number of Additional Strands				Percentage of Class
	1	2	3	4	
0,1,2					0 0
3	2* 0				7.1 0
4	4 1†	1 0			12.2 11.1
5	11 1	2 0			23.2 11.1
6	58 11	20 9	7 6	2 0	35.9 57.8
Total	75 13	23 9	7 6	2 0	23.7 32.9

**F. novae-zelandiae.* †*F. matthewsii.*

Additional strands were present in about one quarter of the *F. novae-zelandiae* samples and in about one third of *F. matthewsii* samples. There were more additional strands in *F. matthewsii* than in *F. novae-zelandiae* and this is in keeping with the results in Table 3. These additional strands were present, as might be expected, in the classes where there were already a comparatively large number of breaks, and in *F. novae-zelandiae* 100 of the 107 samples were in classes 5 and 6.

The distribution of additional strands throughout the collections is not in any orderly manner and is probably at random.

Extent of Abaxial Sclerenchyma

Although the abaxial sclerenchyma may be broken into as many as eleven pieces or into as few as two, the extent to which sclerenchyma is present is such that in some cases there is a nearly complete ring, as the break may be the width of only one, two, or three epidermal cells. Estimates of the extent of subepidermal abaxial sclerenchyma were made on 252 *F. novae-zelandiae* samples and 38 of *F. matthewsii*, from the camera lucida drawings. As the leaves are for the greater part circular a circle divided into 100 parts was used to measure the extent of abaxial sclerenchyma. All measurements

were made to the nearest single unit. A section in which there was a continuous band of sclerenchyma was given an index of 100. Details from the examination of the sections are given in Table 15 for both species where samples are arranged in the seven classes of abaxial sclerenchyma.

TABLE 15—Extent of Abaxial Subepidermal Sclerenchyma in *F. novae-zelandiae* and *F. matthewsii*

Abaxial Sclerenchyma Class	*F. novae-zelandiae*			*F. matthewsii*		
	No. in Sample	Mean Index	Range	No. in Sample	Mean Index	Range
0	41	100		6	100	
1	14	98.2	92–99	2	98.5	98–99
2	23	93.5	88–99	7	94	85–98
3	20	89.3	84–95	3	91.3	90–94
4	31	81.7	66–92	3	88.3	85–91
5	47	73.3	57–86	5	78.2	59–85
6	149	59.8	36–85	12	59.6	45–86

The important features in Table 15 are the gradient of the mean index value from Class 0 to Class 6 which is anticipated from the original class definition, and the range of variation in each class. There is considerable overlapping in the ranges, and sections in Class 4 may have just as much of the circumference sclerenchymatous as sections in Class 1. There is relatively good agreement for mean index value and range between the two species. No particular value is ascribed to this character but it shows that sections classified on the presence and position of breaks in the sclerenchyma are not always dependent on the amount of sclerenchyma.

One other feature which is not apparent from Table 15 is that as the number of additional strands of abaxial sclerenchyma increases there is a slight tendency for the amount of abaxial sclerenchyma to decrease. This might be interpreted as being in line with the reduction in mean index for the classes. Although the samples are small the details are set out in Table 16 for *F. novae-zelandiae* and *F. matthewsii* from pattern 6·1.

TABLE 16—Extent of Abaxial Sclerenchyma in Pattern 6.1 With Additional Sclerenchyma Strands

No. of Additional Strands	*F. novae-zelandiae*			*F. matthewsii*		
	No. in Sample	Mean Index	Range	No. in Sample	Mean Index	Range
0	91	61.9	38–85	12	59.6	49–86
1	36	58.8	36–78	5	54.8	49–64
2	14	55.6	42–68	5	53.6	40–74
3	7	52.1	42–62	3	58.3	49–65
4	1	38	38			

The trend in *F. novae-zelandiae* is not altogether borne out in *F. matthewsii,* the exception being *F. matthewsii* with 3 additional strands, for the other groups the agreement is reasonable.

Abaxial Sclerenchyma Frequencies in Sympatric Distribution of Species

Although *F. novae-zelandiae* collections 43, 44, and 45 from the Awakino River were thought to be of that species only, *F. matthewsii* was present among the plants grown from the seed collections. The sections were cut at the end of the first season, before the plants flowered, and the collections were therefore not as fully sampled as they would have been had it been realised that there were two species present in the collection. The number of *F. matthewsii* or *F. novae-zelandiae* which is recorded in a collection is not indicative of the proportion of each in the collection as a whole. No hybrids were recognised – the separation into two very distinct morphological units being relatively straightforward. The distribution of abaxial sclerenchyma classes is outlined in Table 17.

TABLE 17—Variation in Abaxial Sclerenchmya From Awakino River, Sympatric Distribution

Collection No.	Species	Abaxial Sclerenchyma Class							> 5 Vasc. Bundles	Total
		0	1	2	3	4	5	6		
43	F.m.							3	1	4
	F. n-z						2	2	2	6
44	F.m.		1				1			2
	F. n-z				1		1	3	3	8
45	F.m.						1	3	3	7
	F. n-z								1	1
	Total	0	1	0	1	0	5	11	10	28

The variability in one species is about as great as that in the other, but this is not unexpected as the earlier tests for homogeneity between the classes in both species is fairly good. However, when all the *F. matthewsii* collections are considered and classified firstly on the presence or absence of *F. novae-zelandiae* in the zone in which the collections were made and secondly on abaxial sclerenchyma classes, it can be seen that *F. matthewsii* is more variable when *F. novae-zelandiae* is present in the association than when it is absent. These results are detailed in Table 18.

TABLE 18—Variation in *F. matthewsii* Classified on Presence or Absence of *F. novae-zelandiae* in Locality

	Abaxial Sclerenchyma Class							Collections
	0	1	2	3	4	5	6	
Above F. n-z Zone	0	0	0	0	2	3	16	I, J. K. L. M.
Within F. n-z Zone	6	2	10	4	7	6	29	A. B. C. D. E. F. G. H. N. O, P. Q. R. S.
Total	6	2	10	4	9	9	45	

If then the variation in *F. matthewsii* is greater or less depending on the presence of *F. novae-zelandiae* the homogeneity resulting from the lumping of all *F. matthewsii* samples may not reveal the true picture. While there are only 21 samples in "zone above *F. novae-zelandiae*" distribution, it is still possible, within the author's experience, to record more than three sclerenchyma classes in a sample of this size. It would seem, therefore, that the difference visible in Table 18 is not due to sampling. In *F. novae-zelandiae* collected in areas free from *F. matthewsii,* e.g. lowland coastal areas in North Canterbury, the variability evident is the pattern of variation for the species as a whole.

Abaxial Sclerenchyma in Relation to Number of Ridges

The frequencies in classes of subepidermal abaxial sclerenchyma have been considered in relation to the number of ridges for *F. novae-zelandiae* and the results are to be presented in Table 19.

TABLE 19—Number of Ridges and Frequencies in Abaxial Sclerenchyma Classes in *F. novae-zelandiae*

No. of Ridges	Abaxial Sclerenchyma Class							Total
	0	1	2	3	4	5	6	
1	2 (1.8%	2 (1.8%	5 (4.5%	2 (1.8%	10 (9.0%	11 (9.9%	79 (71.2%	111
2	9 (6.0%	4 (2.7%	9 (6.0%	10 (6.7%	14 (9.3%	22 (14.7%	82 (54.7%	150
3	30 (15.7%	11 (5.8%	13 (6.8%	16 (8.4%	17 (8.9%	23 (12.0%	81 (42.4%	191
Total	41	17	27	28	41	56	242	452

Firstly, the distribution of abaxial sclerenchyma in the ridge classes is not homogeneous, χ^2 resulting in $P = < \cdot 001$. Secondly, there is an increase in the fusion of abaxial sclerenchyma with the increasing number of ridges. This is seen in the drop in percentages in Class 6 for each ridge class and the increase in percentages for those classes with fewer breaks in the abaxial sclerenchyma viz. 0, 1, 2. A good fit to a mathematical model was obtained.

For *F. matthewsii* there are insufficient data to provide a comparison as the 1-ridge class had one sample, the 2-ridge class eight samples, while the remainder were 3-ridged.

This increase in fusion of abaxial sclerenchyma with increasing ridge numbers does not seem to be related to any other phenomena.

Adaxial Sclerenchyma

Adaxial sclerenchyma when present is usually developed in the ridges, though it may be present on the inner edges of the leaf above the uppermost pair of vascular bundles where there are no clear ridges. Sclerenchyma in

the ridges is here referred to as costal to distinguish it from the supra-fascicular adaxial sclerenchyma which eventually unites with the marginal strands.

Costal Sclerenchyma

The presence of costal sclerenchyma and its position in the ridges were classified and the results for both taxa are summarised in Table 20.

TABLE 20—Frequencies of Costal Sclerenchyma in *F. novae-zelandiae* and *F. matthewsii*

No. of Ridges	Position of Costal Sclerenchyma					Total	% Plants With Costal Sclerenchyma
	Median Only	Median + 1 Lateral	Median + 2 Laterals	Lateral Only	Absent		
1	37*	NA	NA	NA	74	111	33.3
	0†	NA	NA	NA	1	1	0
2	64	15	NA	1	70	150	53.3
	0	0	NA	0	8	8	0
3	56	40	17	7	71	191	62.8
	2	14	10	5	45	76	40.7
Total	157	55	17	8	215	452	52.4
	2	14	10	5	54	85	36.5

F. novae-zelandiae. †*F. matthewsii.* NA Not applicable.

It may appear from Table 20 that in *F. novae-zelandiae* there is a trend showing an increasing number of plants with costal sclerenchyma as the number of ridges increases from one to three, but when the total number of costal sclerenchyma present is calculated for each ridge group in relation to the number of sites where sclerenchyma could develop it is found that there is a relatively constant frequency for the whole. In the one-ridge group costal sclerenchyma is present in 33·3% of the ridges, in two-ridge group in 31·7% of the ridges and in the three-ridge group in 33·8% of the ridges.

Dr B. I. Hayman, Applied Mathematics Laboratory, D.S.I.R., to whom these data were referred, in a personal communication, reported that

i. sclerenchyma in the median ridge increases as the number of ridges increases.

ii. sclerenchyma in the lateral ridges is more frequent when there are two laterals than when there is one.

iii. there is a general lack of independence in the occurrence of sclerenchyma in the ridges when more than one ridge occurs.

iv. these (i, ii, iii) do not contradict the constant frequency as a whole, the dependence between the ridges accounting for the discrepancy.

The data for *F. matthewsii* are too few to draw any conclusions.

To complete the range of the variation in the anatomical characters the following table shows the distribution of costal sclerenchyma in relation to the abaxial sclerenchyma classes.

TABLE 21—Frequencies of Costal Sclerenchyma Position in Relation to Abaxial Sclerenchyma Class in *F. novae-zelandiae* and *F. matthewsii*

Abaxial Sclerenchyma Class	Costal Sclerenchyma					Totals	% Plants With Costal Sclerenchyma
	Median Only	Median + 1 Lateral	Median + 2 Laterals	Lateral Only	Absent		
0	16*	11	3	1	10	41	75.6
	0†	2	1	0	3	6	50
1	6	5	0	0	6	17	64.7
	0	1	1	0	0	2	100
2	12	5	2	0	8	27	70.4
	0	2	2	1	5	10	50
3	13	4	1	1	9	28	67.8
	0	0	1	0	3	4	25
4	15	7	2	0	17	41	58.5
	0	2	2	1	4	9	55.6
5	18	5	4	1	28	56	50
	0	3	0	1	5	9	44.4
6	77	18	5	5	137	242	43.4
	2	4	3	2	34	45	24.4
Total	157	55	17	8	215	462	52.5
	2	14	10	5	54	85	36.5

F. novae-zelandiae. †*F. matthewsii.*

Costal sclerenchyma was present in some plants in all but two of the *F. novae-zelandiae* collections and one collection of *F. matthewsii.* In these three cases there were very small samples available for study. No particular pattern for populations can be determined because of the variability in each collection for the number of sites for sclerenchyma to develop (i.e. the number of ridges) and the interaction of ridge number and sclerenchyma occurrence frequencies.

Supra-fascicular Sclerenchyma

In *Festuca novae-zelandiae* supra-fascicular sclerenchyma occurred in 3 plants of the 496 samples examined, and twice in *F. matthewsii.* In *F. novae-zelandiae* two of the sections showed a continuous ring of abaxial sclerenchyma and all showed well developed costal sclerenchyma, while both *F. matthewsii* samples had costal sclerenchyma, and one was pattern 6·1 and the other pattern 5·2. These frequencies are in keeping with the results presented under the heading "Pattern of development in leaf blades".

Attachment of Vascular Bundles to Abaxial Sclerenchyma

None was recorded in *F. novae-zelandiae* samples but in *F. matthewsii* attachment of vascular bundles to the abaxial sclerenchyma occurred in 6 samples with 5 vascular bundles and once in each of the 7 and 10 vascular bundle groups. In the six samples in the 5-vascular-bundle group only the main nerve was connected, but in the two remaining sections the main nerve as well as two lateral nerves were attached to the abaxial sclerenchyma. This fusion was observed in 5 plants of *F. matthewsii* Coll. I. Reference to column 5 of Table 3 shows that in *F. matthewsii* this character develops earlier than it does in *F. novae-zelandiae*. These results are therefore in keeping with the results presented earlier though it should be pointed out that the data in Table 3 for *F. matthewsii* are also from Collection I.

Herbarium Specimens

In the herbarium of the Botany Division, attached to the herbarium sheets are numerous drawings of sections of leaves of the *F. novae-zelandiae* and *F. matthewsii* which have been prepared by Mr V. D. Zotov, and referred to earlier. These drawings were schematically copied on to punch cards and the coding carried out as in the samples from cultivation. Samples from populations from the field were then available for comparison with samples from cultivation.

Data for both species are presented in Tables 22–27, and comparisons made between garden grown and herbarium specimens.

NUMBER OF VASCULAR BUNDLES

Of the 169 samples of *F. novae-zelandiae* all but one had 5 vascular bundles, and the 50 samples of *F. matthewsii* all showed 5 bundles. Neither species showed the range of vascular bundle number recorded in the material from cultivation.

NUMBER OF RIDGES

The number of ridges in the samples is presented in Table 22, where for convenience data on the position of costal sclerenchyma are included.

TABLE 22—Number of Ridges, and Position of Costal Sclerenchyma in *F. novae-zelandiae* and *F. matthewsii*

Position of Costal Sclerenchyma	*F. novae-zelandiae*				*F. matthewsii*			
	No. of Ridges			Total	No. of Ridges			Total
	1	2	3		1	2	3	
Median	66	12	13	91	1	2	2	5
Median and 1 lateral	NA	8	2	10	NA	0	1	1
Median and 2 laterals	NA	NA	10	10	NA	NA	2	2
Absent	32	15	10	57	7	11	24	42
Total	98	35	35	168	8	13	29	50
% Plants with costal sclerenchyma	67.5	57.1	71.5	.....	12.5	15.4	17.2	

NA Not applicable.

Tests for homogeneity between the populations from the herbarium and from cultivation for both species show significant differences, though the tendency for *F. matthewsii* to have more ridges than *F. novae-zelandiae* is maintained. In this latter taxon there was not the same range of ridge numbers as in the cultivated material.

SUBEPIDERMAL SCLERENCHYMA

Abaxial and Adaxial Sclerenchyma

Frequencies in classes of abaxial sclerenchyma are detailed in Table 23. For convenience the frequencies of costal sclerenchyma are also tabled.

TABLE 23—Frequencies in Abaxial Sclerenchyma Classes, and Position of Costal Sclerenchyma in *F. novae-zelandiae* and *F. matthewsii*

Abaxial Sclerenchyma			Adaxial (Costal) Sclerenchyma					
Class	*F. novae-zelandiae*	*F. matthewsii*	Median Only	Median + 1 Lateral	Median + 2 Laterals	Absent	Totals	% Plants With Sclerenchyma
0	61(36.3%)	4(8%)	44*	4	2	11	61	81.9
			2†	0	0	2	4	50
1	8(4.8%)	0	5	1	2	0	8	100
			0	0	0	0	0	0
2	9(5.4%)	2(4%)	6	0	2	1	9	88.8
			0	1	0	1	2	50
3	11(6.5%)	1(2%)	4	2	3	2	11	81.8
			1	0	0	0	1	100
4	9(5.4%)	0	5	1	0	3	9	66.7
			0	0	0	0	0	0
5	10(5.9%)	5(10%)	5	0	0	5	10	50
			0	0	0	0	5	0
6	60(35.7%)	38(76%)	22	2	1	35	60	41.6
			2	0	2	34	38	10.5
Total	168	50	91	10	10	57	168	66.1
			5	1	2	42	50	16

F. novae-zelandiae. †*F. matthewsii.*

Considering first the distribution in classes of abaxial sclerenchyma there is evident, from comparison with Table 9, a marked difference in the proportions in the classes for *F. novae-zelandiae* and a not so marked difference in *F. matthewsii*. A test of heterogeneity on the samples from cultivation and those from the herbarium specimens in *F. novae-zelandiae* gave $\chi_6^2 = 71{\cdot}25$, $P < {\cdot}001$, and for *F. matthewsii* a heterogeneity test gave $\chi_6^2 = 11{\cdot}99$, ${\cdot}05 < P < {\cdot}10$.

In *F. novae-zelandiae* 22 patterns of abaxial sclerenchyma were recorded by comparison with 36 in the cultivated material. This is not surprising if one judges from some of the frequencies in 450 samples and no consequence is attached to this fact. Seven patterns were recorded in *F. matthewsii* herbarium samples by comparison with 19 in the cultivated samples. Table 24 details the frequencies in patterns for 10 collections of *F. novae-zelandiae* and 5 collections of *F. matthewsii.*

At this point it seems appropriate to consider briefly the frequencies of abaxial sclerenchyma pattern occurrence in the 4 groups. Five patterns were common to the four groups viz. 0, 2·9, 5·2, 5·3, 6·1, and of these pattern 2·9 has in general a much lower percentage of occurrence than the remaining four patterns. Nine patterns were common to three groups. Large samples are necessary to record the full range of patterns and the chances of recording some patterns, judging from the 452 garden grown samples, are relatively small though in some of the groups frequencies of patterns were higher than those recorded in the large sample, e.g. pattern 3·8 occurred three times in *F. novae-zelandiae* herbarium specimens and once in *F. novae-zelandiae* from cultivation. To give an estimate of the variability among populations a population variability index for abaxial sclerenchyma classes occurring in each collection where there were 10 or sufficient samples to cover the seven classes. The variability index ranges from 0 to 1. Collections in which all samples are in the same class have an index of 0, collections with two classes present have an index of ·17 through to those collections with samples in all seven classes which have an index of 1. The frequencies of variability indices are presented in Table 25 for both species and from both cultivated and herbarium samples.

In *F. novae-zelandiae* 42 populations were from cultivation and 10 from herbarium material, and in *F. matthewsii* the available populations were very few. In two populations of *F. novae-zelandiae* all samples were pattern 6·1, and have indices of 0. Two collections but both with large samples (20 and 33) showed the maximum variability. The remaining 48 populations were spread over index values ·17 to ·83.

The populations of *F. matthewsii* are too few from which to draw any special conclusions. For the greater part populations of *F. novae-zelandiae,* whether from cultivation or the field, can be expected to show quite a range of variability, and this range of variability will increase to a maximum as the size of the population sample is increased above the level of the sample size generally used here. Grouping of populations on eco-geographical grounds does not reflect a particular order, as lowland populations vary as much as do the high altitude ones, and northern ones as much as central or southern ones.

A table comparable with Table 19 has been prepared from the data from *F. novae-zelandiae* herbarium specimens to show the changes in class frequency of abaxial sclerenchyma with changes in number of ridges.

A gradient for reduction in frequency in Class 6 with number of ridges is evident. At the Class 0 end there is no marked gradient for increase in frequency with increasing number of ridges but there is a slight tendency to increase.

TABLE 24— Collections of *F. notae-zelandiae* and *F. mattheusii* From Herbarium Specimens Showing Frequencies of Abaxial Sclerenchyma Pattern *F. notae-zelandiae*

Collection	Abaxial Sclerenchyma Pattern																								Total
	0	1·1	1·2	1·3	2·2	2·3	2·4	2·6	2·9	3·1	3·2	3·5	3·8	3·10	4·1	4·2	4·3	5·1	5·2	5·3	6·1	
Volcanic Plateau	7	1			1					1		1			2	2	1			1	16	33
The Lane, Awatere Valley	4			1					1					1				1			2	10
Jollies Pass	2					1												1			2	6
Broken Riv. Area	14	1	1								1		1		1						1	20
Cave	6																				4	10
Mt. Cook Station	4				1	1											1	1			5	13
Duntroon side of Dansey Pass	3																			1	2	6
Duntroon	4				1								1								4	10
Central Otago	3			1			1			1									1		1	8
Dunstan Mts.																					6	6
Total	47	2	1	2	3	2	1	0	1	2	1	1	2	1	3	2	2	3	1	2	43	122
F. matthewsii																						
Arthur's Pass																					3	3
Mt. Cook																					3	3
Kirkliston Range	1								1												1	3
Mt. Ida	3							1											1	1	3	9
Dunstan Mts.																				1	23	24
Total	4	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	2	33	42

TABLE 25—Frequencies of Population Variability Indices for *F. novae-zelandiae* and *F. matthewsii* Collections

Variability Index	*F. novae-zelandiae*		*F. matthewsii*		Total
	Cultivation	Herbarium	Cultivation	Herbarium	
0	1	1			2
0·17	6	1	1	1	9
0·33	12	1			13
0·5	12	2		1	15
0·67	6	2	4		12
0·83	4	2			6
1·0	1*	1*			2
Total	42	10	5	2	59

*Large populations.

TABLE 26—Frequencies in Abaxial Sclerenchyma Classes in Relation to the Number of Ridges in *F. novae-zelandiae* From Herbarium Specimens

No. of Ridges	Abaxial Sclerenchyma Class							Total
	0	1	2	3	4	5	6	
1	33 (33.7%	4 (4.1%	4 (4.1%	4 (4.1%	7 (7.2%	6 (6.1%	40 (41.0%	98
2	15 (41.9%	0	2 (5.7%	3 (8.6%	0	3 (8.6%	12 (34.3%	35
3	13 (37.1%	4 (11.4%	3 (8.6%	4 (11.4%	2 (5.7%	1 (2.9%	8 (22.8%	35
Total	61	8	9	11	9	10	60	168

Additional Strands of Abaxial Sclerenchyma

In *F. novae-zelandiae* additional strands of sclerenchyma were seen in 3 samples. Two of these are in accord with the expectation from cultivated material, the third occurred in pattern 1·1 in a plant from Broken River. This did not fit the predictions and it is emphasised that although a large range of variation was encountered in the material from garden grown plants the whole of the possible range of variation is obviously not complete. The frequency of occurrence in herbarium material is nowhere near as great as that in material from cultivation. Two samples of *F. matthewsii* had additional strands and these were in patterns 5·3 and 6·1 and are in accord with the results from cultivated material.

Costal Sclerenchyma

A complex pattern of costal sclerenchyma is revealed in the herbarium samples (Table 23) as was the case with samples from garden grown plants. The sampling for *F. matthewsii* is too small to show any evident

trends, but by comparison with the cultivated material, the herbarium specimens showed a percentage presence for costal sclerenchyma, based on the number of sites with sclerenchyma, in the total available, of 9·3% by contrast with 26·5% in the cultivated, a quite marked difference.

In *Festuca novae-zelandiae* none of the statistical propositions agreed with those of the plants from cultivation (see p. 496) except the lack of independence in the occurrence of sclerenchyma in the ridges when there is more than one ridge. On the whole there was a higher percentage presence of costal sclerenchyma in the samples from herbarium specimens than in the samples from cultivated plants. In the 1-ridge class 67·5% of the ridges had sclerenchyma present, in the 2-ridge class 40% of the ridges had sclerenchyma, and in the 3-ridge class sclerenchyma was present in 44·8% of the ridges.

Percentage presence of costal sclerenchyma for each population based on the number of ridges with sclerenchyma in the total number of ridges was calculated. Presence ranged from 0 to 83%, and the data are summarised in Table 27 from the populations included in Table 25.

TABLE 27—Frequencies in Percentage Classes of Costal Sclerenchyma in *F. novae-zelandiae* and *F. matthewsii* Collections

% Costal Sclerenchyma	*F. novae-zelandiae*		*F. matthewsii*		Total
	Cultivation	Herbarium	Cultivation	Herbarium	
0	0	0	0	1	1
1–20	10	0	0	1	11
21–40	24	3	5	0	32
41–60	5	3	0	0	8
61–80	3	3	0	0	6
81–100	0	1	0	0	1
Total	42	10	5	2	59

Supra-Fascicular Sclerenchyma

Three samples were recorded in *F. novae-zelandiae* in sections which showed well developed costal sclerenchyma and nearly complete rings of abaxial sclerenchyma. In *F. matthewsii* one sample had supra-fascicular sclerenchyma in pattern 6·1 and costal sclerenchyma in the median and two lateral ridges, which is within the expected range.

Attachment of Vascular Bundles to Abaxial Sclerenchyma

Five samples of *F. novae-zelandiae* showed vascular bundles connected to the abaxial sclerenchyma while none were reported in the garden grown material. Three samples were in class 0 the other being in patterns 4·1 and 6·1. The occurrence in class 0 is within predictable range the others being outside.

In *F. matthewsii* 3 samples with connections to abaxial sclerenchyma were observed. Two were from Ben Lomond, Queenstown, at high elevations and one from Fox Glacier. The samples occurred one each in classes 3, 5, and 6, in and are within the range seen in garden material.

DISCUSSION

The variation in the characters studied has been detailed at length and has illustrated some of the problems associated with the use of these anatomical characters as taxonomic criteria in these two species. The general conclusion is that all the available characters need to be considered as statistics, but their use is made more complex by the apparent disagreement between the results from garden grown material and the results from herbarium specimens. Then, too, the intra-plant variation is quite marked in some plants.

Considering again the "Patterns of Development in Leaf Blades" and the detail in Table 3 there are certain features worthy of more consideration. That there is in early development a common pattern of abaxial subepidermal sclerenchyma has been pointed out and this is common to both species. There was an exception in that a high altitude race of *F. novae-zelandiae* did not show the common 6·1 pattern but a complete ring of sclerenchyma at the highest position sampled. The variation down a leaf blade may be great or small in abaxial sclerenchyma. Changes in number of ridges and vascular bundles occur. Presence of costal sclerenchyma appears dependent on a number of factors. There is no really uniform pattern present, though the presence of trends as previously outlined in Fig. 4 is apparent.

Some leaves have five vascular bundles laid down early in development and this number may not change in the leaf, in others the number of bundles increases a short distance down from the apex. The number of vascular bundles may or may not reduce towards the base. Soper and Mitchell (1956) observed in *Lolium perenne* new intermediate vascular bundles being formed " . . . only while the leaf is increasing rapidly in width, that is, during the initial period of apical and marginal growth of the primordium before cell division becomes restricted to the intercalary meristem at the base of the leaf. Thus in the fully elongated blade it is only towards the tip that there are fewer veins". The development of bundles in *F. novae-zelandiae* and *F. matthewsii* is seemingly spread over a longer time than in *Lolium perenne* and is somewhat like that of *Zea mays* (Sharman, 1942).

Again, in *Lolium perenne,* with the initiation of vascular bundles there is also the formation of ridges as well as the sclerenchyma strands above and below the larger bundles (Soper and Mitchell *op. cit.*). In *Festuca novae-zelandiae* ridges usually increase in number relatively slowly, and in *F. matthewsii* the increase is more rapid. Quite often in *F. novae-zelandiae* there is no increase in ridge number from apex to base, and in two samples there was an increase followed by a decrease.

Of the various changes observed within a leaf the most striking is in the extra-fascicular sclerenchyma. The attachment of the vascular bundles to the abaxial sclerenchyma (girders of some authors) in *F. novae-zelandiae* is restricted to the basal portion of the leaf, but commences earlier in the development of *F. matthewsii* blades. Costal sclerenchyma is usually absent in the upper part of the blade, but at the base is present in large quantities.

in some cases almost to the extent of forming a completely united strand which almost merges with the long marginal strands so that adaxial and abaxial sclerenchyma are nearly continuous.

In the abaxial sclerenchyma fusion of strands towards the base is the most evident feature, but in two plants of *F. novae-zelandiae* (G.869 and G.870) there were no breaks in sclerenchyma from apex to base. Fusion of sclerenchyma strands may take place at any point (cf. Fig. 5) and changes to a previous or similar condition may occur. The causes of these changes and the variation which they produce is of some concern as this single character is very easily seen and one to which there is an obvious tendency to give weight.

Hackel (1882) observed that in *F. ovina* vars. *genuina* and *duriuscula* an unbroken sclerenchyma ring occurs, but breaks are not uncommon especially in leaves formed early in the season. As in *F. varia* ssp. *pumila,* var. *genuina* has separate sclerenchyma strands and var. *rigidior* has fused strands, he goes on to say that the presence of a sclerenchyma ring has not the diagnostic value that he originally supposed.

Observations on the abaxial sclerenchyma are also reported by Hackel from experiments he conducted. *Festuca ovina* vars. *genuina, pseudovina* and *glauca* and *F. rubra* were grown in pots under two contrasting conditions, A: sand, low water, and full sun; B: heavy soil, plenty of water and shade. The sclerenchyma cells had much thicker walls in the series grown in sand under dry hot conditions than those grown in the moist conditions. *Festuca ovina* var. *genuina* and var. *glauca* grown in moist conditions showed breaks in the sclerenchyma ring on both sides of the main nerve whereas under the dry hot treatment no breaks were present. In *F. ovina* var. *pseudovina* and *F. rubra* there were no changes in the sclerenchyma pattern. Hackel interprets this to mean that not all species (*sic*) are independent of the effects of the environment on the mechanical tissues. The two varieties which showed the differences usually had continuous, or nearly so, abaxial sclerenchyma in contrast with the disjunct sclerenchyma of the two other taxa. From these trials Hackel concluded (p. 29) that histological characters, as all others, must be tested for variation and constancy. Further, Hackel (p. 31) discusses the heritability of histological characters and concluded that if they were not truly heritable then they would have no value in species diagnosis, and asserts that the histological characters are of diagnostic value. In the trial described he saw that only the closed ring of sclerenchyma altered under the moist shaded conditions, and as the ring of sclerenchyma showed the greatest departure from the original dispositon of the sclerenchyma (though this original disposition is not stated anywhere in the text), he concluded that conditions which are unfavourable for sclerenchyma development (shade and moisture) arrest its development at an earlier (incomplete ring) stage.

Before proceeding further with Hackel's conclusions it is appropriate to relate the work of Mitchell and Soper (1958) to this problem. They showed that the conditions of light intensity and temperature under which the leaf has grown rather than the conditions under which the leaf was initiated were the most important feature in defining the ultimate length and shape

of the leaf. *Festuca novae-zelandiae* and *F. matthewsii* are slow growing perennials which produce leaves all the year round, although more slowly in winter. The pattern of abaxial sclerenchyma at the apex of the leaf is common to both species and is probably genetically determined. The interaction of the environment and the early initiated 6·1 sclerenchyma pattern is of interest, but in the absence of controlled experiments some tentative conclusions can be drawn from available data. It seems possible that changes in environmental conditions from the time the apex developed until the basal part of the blade finally developed could be responsible for some of the variation within the leaves. There is, however, one other tendency common to all the plants, i.e. in the basal part of the leaf there is more sclerenchyma than there is above. It can also be seen that once sclerenchyma tissue has developed where there was previously none there is only rarely a return to the earlier condition (see Fig. 5), though in *F. novae-zelandiae* after sclerenchyma had been formed, seven strands reverted to the unsclerosed condition (three in one plant) in 66 main strands. Environmental influences cannot explain all the variation in abaxial sclerenchyma in a leaf. There are cases of single non-sclerenchymatous strands (see G. 875 1, 2) extending down the blade deep into the sclerenchyma; then too, abundant sclerenchyma develops at different levels in the leaves. The uniform environment garden subjected all plants to more or less the same conditions, though time of sampling may have affected the results as in time more and newer leaves were emerging and becoming part of the available population from which to draw the samples. The evidence from the garden grown material shows that in one environment, at the sampling point, the complete range of abaxial sclerenchyma patterns are present. Clearly, then, environmental effects are not the complete answer to the variation observed.

Attention has already been drawn to the abundant sclerenchyma at the base of the leaf. This is seen in the continuous ring of abaxial sclerenchyma, costal sclerenchyma in all the ridges, long marginal strands, and the attachment of the vascular bundles to the abaxial sclerenchyma, which is in marked contrast to the condition in the upper portion of the leaf where the sclerenchyma is much less abundant.

It is reasonable to assume that the differentiation of sclerenchyma cells is under genetic control. Timing of the process of differentiation could vary and in some leaves the locus of full sclerenchyma differentiation could begin earlier than in others giving rise to more sclerenchymatous tissue higher up the leaf. Prat (1951) in discussing histological gradients in grasses points out that the tip of the grass leaf which is that formed first is poorly differentiated and that the base of the leaf is extensively differentiated. A histological gradient of sclerenchymatous tissue is present in the leaves of both *F. novae-zelandiae* and *F. matthewsii* and Prat's suggestion that such gradients are due to a gradient in the concentration of growth substances possibly applies here. These suggested processes may not be fully effective and sclerenchyma differentiation may not be complete at the base of the leaf where sclerenchyma broken into two, three, or four strands may result. At this point Hackel's discussion can be recalled and his statements (op. cit. p. 31) considered further. In *Festuca ovina* vars. *genuina* and *glauca* Hackel concluded that the formation of complete rings of scleren-

chyma from the earlier condition of broken rings was delayed by processes unfavourable to sclerenchyma development.

Hackel's solution does not in fact differ from that presented here although he did not give all the data necessary to reach complete agreement. The emphasis he placed on the conditions unfavourable for sclerenchyma development, shade and moisture, will not be considered further here.

The heterogeneity tests on the frequencies in the classes of abaxial sclerenchyma showed good agreement between the two species from garden-grown material. The conclusion can be drawn that both species show the same kind of variation for abaxial sclerenchyma. It is therefore not possible to use this character alone as a taxonomic one at the specific level. Dependence on statistics e.g. mean number of vascular bundles, or mean number of ridges is not satisfactory more especially if the number of plants is few. The complex interaction between number of ridges and costal sclerenchyma and both of these with the abaxial sclerenchyma classes renders all the criteria very difficult to use. Reference must be made again to the lack of agreement between samples from herbarium material and garden grown plants. There was so little agreement that some explanation must be forthcoming. Differences in the distribution of the number of ridges, range of vascular bundle number, in distribution of abaxial and costal sclerenchyma classes all point to such a wide divergence as to suggest that one set of data bears no relation to the other. While it may appear difficult to offer any solution to this state of affairs there are some factors which must be considered.

For distribution in classes of abaxial sclerenchyma, *Festuca novae-zelandiae* and *F. matthewsii* from herbarium collections were heterogeneous by comparison with the homogeneity of samples from garden-grown material, and when all four were tested they were significantly heterogeneous. This heterogeneity might be interpreted as due to the places of collection as this is the main difference, and that environmental differences will account for the differences between natural populations and garden grown ones.

The samples from the herbarium specimens are not as representative of the populations as are those from cultivation, sample size ranging from 1 to 33. Further, the main differences in *F. novae-zelandiae* for abaxial sclerenchyma classes lie in classes 0 and 6, and when these are excluded and a heterogeneity test conducted on classes 1 to 5 there is a reasonable fit ($P > \cdot 25$) for data from herbarium specimens and garden grown plants. This nevertheless still leaves a large amount of the discordance unexplained. Facile though this following explanation may seem, it is concluded from an examination of Hackel's conclusions and the conclusion reached from the data presented on patterns of development within leaves, that the differences are more apparent than real and can be accounted for by the interaction of the environment and the genetic structure of the species.

Hybridisation between the two taxa is possible as both are outcrossing species and have overlapping ranges, though marked ecological preferences. An experimentally produced F, *F. matthewsii* × *F. novae-zelandiae* has flowered this summer (1959/60), but no indication can yet be given of its fertility. No natural hybrids have been seen in the field and both species preserve their identities when the distribution is sympatric.

Should hybrids occur, any effects of hybridisation on leaf anatomy will probably not be detectable in abaxial sclerenchyma pattern, unless there is a marked continuation of evidence similar to that produced in Table 18 where variation was less in *F. matthewsii* collected from zones where *F. novae-zelandiae* was absent. Should this be so the effects will be seen in *F. matthewsii* rather than in *F. novae-zelandiae* in which there is an extensive variation in this character. The number of vascular bundles and the number of ridges will be most difficult to use in estimating hybridism, as also will the costal sclerenchyma position and frequencies.

The relationship between the high altitude race of *F. novae-zelandiae* collected from Mt Lyndon and Mt Harper and the remaining *F. novae-zelandiae* assemblage is not understood, nor are there sufficient data to work on, except that this race, ecotype, or species is readily discernible on habit and panicle characters.

Conclusion

The conclusion is inevitable that anatomical characters, varying as much as they do, are for the greater part unusable as taxonomic criteria in the two species of *Festuca* studied. In this instance a leaf section, or even several sections, would lead to the conclusion that the specimen belonged in the group *Festuca novae-zelandiae – F. matthewsii* (a decision which can be reached by other simpler methods) and in this respect the author agrees with Parodi (1953) that *groups of species* can be recognised from leaf anatomy.

The problem of leaf anatomy for the genus *Festuca* as a whole still remains, but until a thorough exploration has been made in other cases, the use of leaf anatomy as a specific diagnostic character is suspect.

Acknowledgments

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THE NUTRIENT CONTENT OF *Pinus Radiata* TREES

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Summary

The needles, branches, bark, and wood from 8 radiata pine trees have been sampled and analysed for N, P, K, and Ca. From the results variations between and within parts of the tree have been studied. Also totals for the parts of the tree and the whole tree have been calculated.

The N, P, and K contents of bark increase up the stem; Ca decreases.

The highest levels of N, P, and K in wood are found in the outer ring of sapwood and in the heartwood transition zone near the top of the tree; the highest level of Ca is in the heartwood.

In a mature tree, the crown (branches plus needles) contains less than 10% of the total dry matter and less than 40% of the total nutrient content. As a result greater quantities of nutrients are removed from a site when a stand is clear felled than are left in the slash.

INTRODUCTION

There have been many and extensive studies of the organic compounds present in the wood and bark of trees, but, in contrast, there are few published data on their mineral nutrient composition. Figures for the nutrient content of wood ash, tree seedlings, and foliage have been given by several authors (see Leyton 1958) but in calculating the nutrient composition of whole trees Rennie (1955) found that the only sources of information were a number of papers published in Europe during the latter half of the 19th century. More recently Ehwald (1957) has included the results of several Russian authors in his comparison of the dry matter production and the nutrient uptake by forest stands and field crops. Ovington (1957, 1959), Ovington and Madgwick (1959), and Wright and Will (1958) have reported figures for stands of trees in Great Britain.

Although the nutrient content of wood may have little effect on its physical properties or its uses, it is of some importance to know the quantities of mineral nutrients in a tree and their distribution between the parts of a tree. Studies on tree physiology must include the uptake of mineral nutrients, their primary location within a tree and any subsequent translocations. Also, as Rennie (1957), has stressed, if the total amount of any one nutrient in a healthy mature crop of trees exceeds the amount available in the rooting zone, corrective fertiliser applications should be applied before deficiency symptoms or decreased growth occur.

An intensive programme of research on radiata pine (*Pinus radiata*, D. Don) both as a growing tree and as a timber is being carried out at this Institute. This paper reports the total amounts of nutrients in a tree (and in a crop of trees), and their distribution between and within the parts of a tree are given.

SITE OF INVESTIGATIONS

In a study of the physical properties of radiata pine timber, trees have been felled in Compartment 49, Kaingaroa Forest. Trees from the same site were used in this study, the site quality being IIA. The compartment was planted in 1928 and has been left unthinned, but mortality due to natural suppression and attacks by the wood wasp *Sirex noctilio* Fabr. have considerably reduced the original stocking. The stand is representative of areas being felled for timber and pulp production. Details of the stand in 1954 were:

Age	26 years.
No. of trees	122 per acre.
Mean diam. breast height o.b.	16·3 in.
Mean height	116 ft.
Total basal area	176 sq. ft. per acre.
Volume	6,900 cu. ft. per acre.

The area is about 50 miles from the sea at an altitude of 1,700 ft. It has a mean annual temperature of 50°F and an annual rainfall of 60 in.

The soil is derived from composite rhyolitic ash beds – a few inches of pumice sand from the Kaharoa shower overlies an old soil developed on pumice sands of the Taupo shower. It is a strongly leached soil of low fertility, which is classified as Paengaroa shallow sand (see N.Z. Soil Bureau 1954).

METHODS OF SAMPLING TREES

Eight trees (6 mean, 1 dominant, and 1 suppressed) were felled and samples of the needles, branches, bark, and wood were taken from each as follows:

Needles

From the first four trees (felled in 1954–55) samples of all age groups present were taken from various parts of the crown. Analysis of these showed the variations in composition to be expected within the crown (see Will 1957) and composite samples were taken from each of the last four trees (felled in 1957). In each case the foliage taken was a known fraction of the total on the tree. This varied between 20% and 100% depending on size of the tree's crown.

Branches

A similar range of percentage of the branches, both dead and alive, was taken from each tree.

Wood

Five discs were cut from each stem – from the butt and at each succeeding fifth internode. Each disc was divided into heartwood and at least two zones of sapwood. The samples from the first four trees were analysed individually but the others were mixed to give composite samples representative of (1) the outer five rings of sapwood, (2) remainder of sapwood, and (3) the heartwood, of each tree.

Bark

The bark was stripped from each of the wood sample discs. Surface areas were measured and dry weights found. Samples from the last four trees were mixed to give composite sample representative of the total bark on each stem.

METHODS OF ANALYSIS

After drying, grinding, and mixing, all samples were analysed for nitrogen, phosphorus, potassium, and calcium. The methods of Metson (1956) for plant litters were used except for P, which was determined colorimetrically.

RESULTS AND DISCUSSION

Figures for the variations in composition found within the needles, bark and wood of a tree have been obtained from the four trees which were extensively sampled. The results from all eight trees have been used in calculating the average composition of the parts of a tree and the figures for a stand of trees.

Of the differences found between trees, some of the greatest were between mean trees felled at the same time; because of this no attempt has been made to study the influence of season or of crown size on the nutrient composition of parts of a tree.

Needles

Details of the variations within and between the first four trees have already been published (Will 1957). Average figures for the weight and composition of needles on a tree are given in Table 1.

Branches

The average weight and composition of branches on a tree are given in Table 1. The concentrations of all nutrients except Ca are lower in the branches than in the needles and the overall composition of the branches is very similar to that of the bark.

TABLE 1—Average Weight and Composition of Parts of Eight 26–29 Year Old Radiata Pine Trees

	Dry Weight (lb)	% Oven-dry Sample			
		N	P	K	Ca
Needles	33	1.32	0.180	0.90	0.12
Branches	86	0.30	0.018	0.20	0.15
Bark	208	0.17	0.020	0.17	0.13
Wood	1,440	0.05	0.007	0.065	0.033

Bark

In Fig. 1, the graph shows how the weight of bark per sq. in. of stem surface varied from the butt to the top of the trees. There is little or no variation within the green crown but below this there is a slow increase followed by a sharp increase near the butt. In this respect radiata pine is more like Corsican than Scots pine. (Wright and Will 1958).

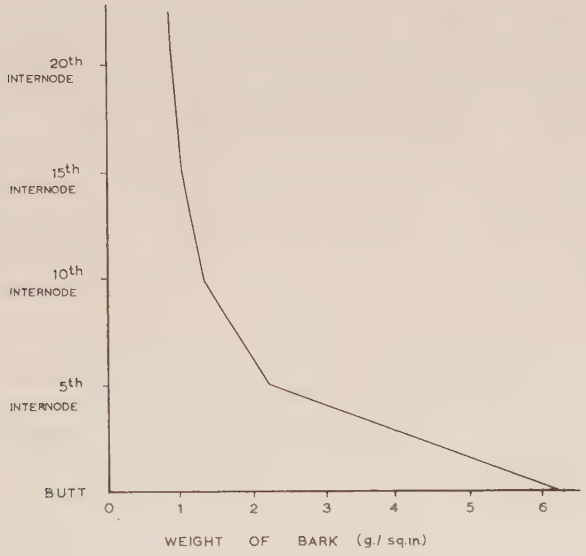

FIG. 1—Variation with height, of weight of bark per sq. in. of stem surface.

The bark from four of the trees was subdivided into (a) the outer dead brown bark, as separated by the last periderm from (b) the inner living bark (secondary phloem). These were analysed separately from each disc in order to study any variations in their composition. Average results are given in Table 2. The levels of N, P, and K in the living bark show little variation with height but the Ca content decreases progressively up the stem. This is in contrast to the dead bark, in which the Ca content remains nearly constant but the N, P, and K levels increase up the stem. As the living bark constitutes (on a dry-weight basis) only a third of the total bark within the green crown, and a twenty-fifth at the butt, variations in the content of the total bark follow closely those in the dead bark. A similar rise in the N, P, and K contents up the stem has been found with Corsican and Scots pine (Wright and Will 1958) but these species show a low level of Ca at the butt where radiata pine has its highest level. The average weight and content of bark are given in Table 1.

TABLE 2—Variation in Composition of Radiata Pine Bark with Height
(Average results from four trees)

	% Oven-dry Sample			
	N	P	K	Ca
Living bark—				
20th internode	0.52	0.10	0.94	0.13
15th internode	0.52	0.10	1.07	0.11
10th internode	0.52	0.10	1.00	0.23
5th internode	0.47	0.09	0.84	0.53
Butt	0.48	0.09	0.80	0.94
Dead bark—				
20th internode	0.47	0.06	0.60	0.09
15th internode	0.22	0.04	0.55	0.08
10th internode	0.20	0.03	0.08	0.08
5th internode	0.14	0.01	0.06	0.09
Butt	0.12	0.007	0.03	0.12

Wood

The nutrient composition of wood varies considerably within a tree. The variations found are shown diagrammatically in Fig. 2a for Ca and N, and in Fig. 2b for P and K. These variations are shown across the tree at various internode levels and as they are presented on a modified three-dimensional graph, the variations with height for a particular growth layer can also be shown on the same diagram.

The highest N, P, and K concentrations are found in the outer growth ring of the sapwood, with a very sharp drop in the content of these nutrients towards the heartwood. When the heartwood boundary is reached the level of P again drops sharply; the level of K also drops but not to the same extent. In contrast to these nutrients the level of Ca is low in the outer sapwood rising to a maximum in the heartwood.

Within the green crown the discs have, on the average, higher N, P, and K contents but a lower Ca content. This has no doubt, resulted from the more active transport of N, P, and K within the green crown, the decreasing cross section of the stem and the decreasing amount of heartwood present.

These levels and variations are very similar to those found in Scots and Corsican pines. Wright and Will (1958) reported that in these species a zone of higher nutrient content was present just outside the heartwood. This "drywood" or "transition" zone, where heartwood formation is taking place is usually one annual ring wide in radiata pine. Work has been done on the moisture content and resin content changes in this zone, and on the formation of certain organic constituents with actual heartwood formation. (Harris 1954).

In this drywood zone there are indications that the N, P, and K contents are high when compared with the adjacent heartwood and sapwood zones. The higher concentrations of these elements in this zone occur near the top of

the tree where heartwood of a younger "cambial age"* is being formed. Even Ca, which shows a decrease in this zone for older heartwood, has a high concentration in the upper levels of the tree for young heartwood. Although further detailed work is needed, the above does indicate that considerable metabolic activity and transportation of chemical substances are taking place in this zone.

From these figures, it appears that Ca shows a marked build up from the cambium to the heartwood, with the highest concentration in the heartwood. Ca is a necessary part of the enzyme system for translocation of carbohydrates and is directly concerned in starch-sugar changes. It is unlike other elements in that once it is deposited it appears to be of little value for later new growth. However, the change in concentration at the heartwood "transition" zone would indicate an active zone for Ca in which the Ca is possibly re-absorbed and finally deposited as an end product in the heartwood.

On the other hand P and K are found in regions of greatest metabolic activity and only in small amounts in the non-living tissue of the heartwood. The concentration of P and K in the "transition" zone would appear to indicate metabolic activity, the activity being most marked for K, in the upper part of the tree. K can act as a catalyst in the formation of organic compounds and it may therefore be taking an active part in the formation of heartwood constituents.

Nitrogen is at its highest level in the outer sapwood but its concentration remains relatively stable from inner sapwood to heartwood. The "transition" zone has a tendency to show an increase of nitrogen in the upper part of the tree.

Average figures for zones in each of the last four trees (felled in 1957) are given in Table 3 and these confirm the more detailed picture in Fig. 2.

Figures for the total wood in a tree are given in Table 1. These figures show that while 26 year old radiata pine in New Zealand produces a weight of wood far in excess of that produced by 28 year old Scots and Corsican pines in Scotland (Wright and Will 1958), the percentage mineral composition of the wood is very similar.

TABLE 3—Average Composition of Zones of Wood from Four 29-year-old Radiata Pine Trees Felled in 1957

	% Oven-dry Sample			
	N	P	K	Ca
Outer 5 rings of sapwood	0.051	0.010	0.090	0.024
Remainder of sapwood	0.041	0.007	0.059	0.032
Heartwood	0.046	0.003	0.045	0.036

In Appendix I, the variation of nutrient content (mean and range) for within and between trees is given for the various zones and for the different internode levels.

*"Cambial age" is determined by the number of annual growth layers from the pith at a particular level.

CALCIUM NITROGEN

FIG. 2a—Mean distribution of calcium and nitrogen within four 26-year-old radiata pine trees from Compt. 49, Kaingaroa Forest, felled in 1954 and 1955. 'Ht' is the heartwood zone; 'TZ' is the heartwood transition zone; percentage based on oven-dry weight of sample.

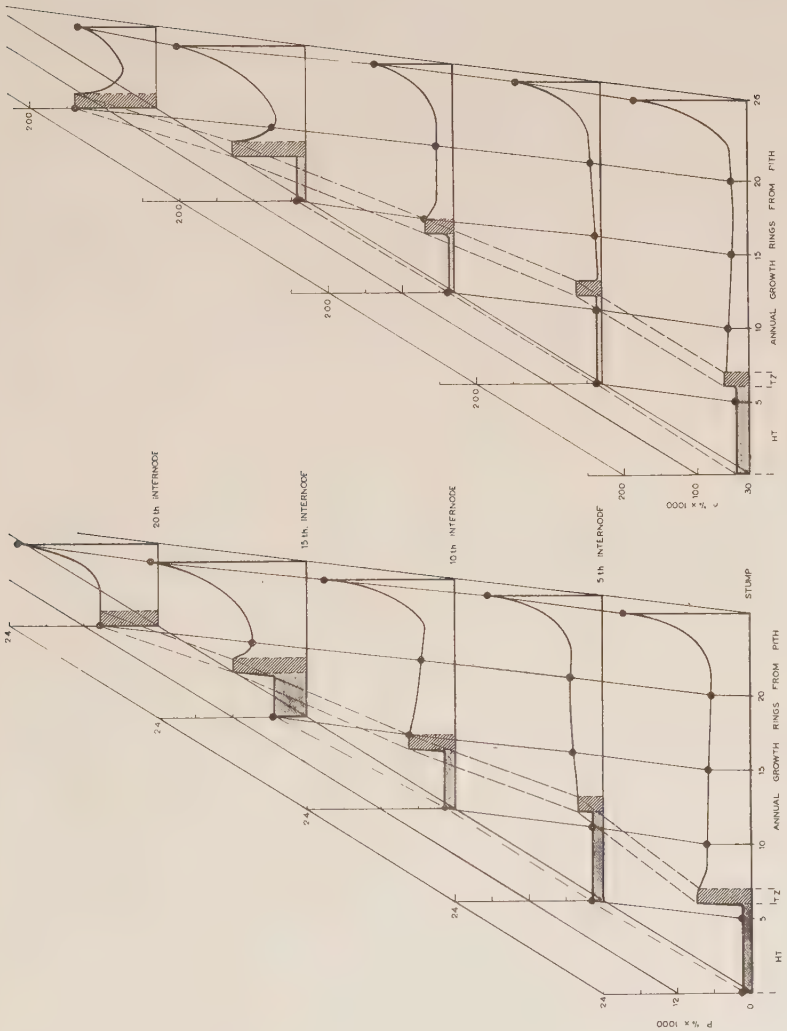

FIG. 2b—Mean distribution of phosphorus and potassium within four 26-year-old radiata pine trees from Compt. 49, Kaingaroa Forest, felled in 1954 and 1955. 'Ht', 'TZ', and %, as for Fig. 2a.

COMPARISON WITH BARK AND WOOD FROM YOUNGER TREES

As part of another study (unpublished) 10 trees were felled in a stand 8 years after planting. Two discs were cut from each tree – one at a height of 6 ft and one from about the middle of the green crown. Each disc was divided into the bark, last ring of sapwood, and remainder of wood.

Average results for the 10 trees are given in Table 4. These younger trees show higher levels of N, P, and K, especially in the disc from the green crown: the absence of heartwood and dead bark will have been partly responsible for this, but it also reflects the greater vigour of a young fast growing stand. Otherwise the pattern of distribution is similar to that found in the older trees.

TABLE 4—Average Composition of Bark and Wood from Ten 9-year-old Radiata Pine Trees

	% Oven-dry Sample			
	N	P	K	Ca
Bark				
Crown	1.00	0.135	1.04	0.09
Butt	0.39	0.068	0.57	0.20
Wood				
Crown 1. Outer ring	0.15	0.031	0.27	0.016
2. Remainder	0.11	0.017	0.17	0.016
Butt 1. Outer ring	0.09	0.026	0.23	0.030
2. Remainder	0.06	0.007	0.045	0.036

COMPOSITION OF WHOLE TREES

The data in Table 1 have been used to prepare Table 5, in which figures for the distribution of dry matter and nutrients between the parts of a tree are given.

TABLE 5—Percentage Distribution of Dry Matter and Nutrients Between the Parts of a Tree

(Based on eight 26–29-year-old Trees)

	Percentage of Total				
	Dry Matter	N	P	K	Ca
Needles	2.5	25	24	18	4
Branches	5.5	14	8	10	14
Bark	12.0	20	19	20	30
Wood	80.0	41	49	52	52
	100.0	100	100	100	100

The needles, branches, and bark represent only 20% of the dry matter in a tree but they contain about 50% of the nutrient content. It should be noted that the needles, which make up only a fortieth of the total weight of a tree, contain a fifth of the N, P, and K.

Table 6 gives the distribution of dry matter and nutrients between the logs removed and the slash remaining when a stand is clear felled. In calculating these values a stump height of 6 in. and utilisation to a 4 in. top have been assumed.

TABLE 6—Weights and Percentages of Dry Matter and Minerals in Logs and Slash of Clear Felled Radiata Pine (site quality IIA), Kaingaroa Forest

	Weights (lb/ac.) and Percentages of Dry Matter and Minerals in Logs and Slash				
	Dry Matter	N	P	K	Ca
Slash	18,000 (9%)	83(42%)	9(36%)	59(29%)	22(19%)
Logs	180,000(91%)	114(58%)	16(64%)	141(71%)	94(81%)

CONCLUSIONS

Nutrient levels for N, P, and K are constant in the sapwood at a particular height in the tree, except for high concentrations in the growth layers immediately adjacent to the cambium. These nutrient levels increase with height within the tree. The nutrient content of the heartwood is generally lower than that of the sapwood.

Ca is an exception to these trends. There is a general increase in Ca content from the cambium to the heartwood, with the highest concentration in the heartwood at the butt.

The high nutrient levels in the transition zone surrounding the heartwood are indicative of metabolic activity in which the elements N, P, and K appear to play an essential part. It is suggested that radioactive isotopes of P and K could be used as valuable tools in elucidating some of the physiological processes involved in heartwood formation.

Even though only 10% of the dry matter in the mature crop of trees is left behind in the slash, greater percentages of all nutrients are returned to the soil by this means, because needles and twigs contain higher nutrient concentrations than wood. The slash contains 19% of the Ca, 29% of the K, 36% of the P and 42% of the N in the crop.

The quantities of nutrients reaching the soil in litter and rainwater, during the life of the trees, have already been studied (Will, 1959). Further work on this aspect is being carried out and a future paper will consider the nutrient cycle during the life of a tree crop and the removal of nutrients due to thinning and clear felling. These quantities will be related to the quantities available and potentially available in the rooting zone of the soil.

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APPENDIX I

Variation of Nutrient Content Within and Between Radiata Trees for Various Zones and Internode Levels

Based on Eight 26–29-year-old Trees From Kaingaroa Forest

(Sections C and D on Internode Levels are Based on Four Co-dominant Trees Only)

	No. of Trees	% Oven-dry Sample			
		N	P	K	Ca
A. WHOLE TREE					
Mean: All trees	8	0.054	0.007	0.065	0.033
Range: Dominant	1	0.046	0.006	0.067	0.028
Suppressed	1	0.048	0.007	0.066	0.028
Co-dominants	6	0.041–0.083	0.006–0.009	0.058–0.081	0.031–0.036
B. SAPWOOD & HEARTWOOD FOR WHOLE TREE					
(i) *Outer 6 rings Sapwood*					
Mean: All trees	8	0.059	0.010	0.090	0.025
Range: Dominant	1	0.051	0.009	0.089	0.026
Suppressed	1	0.053	0.011	0.084	0.021
Co-dominants	6	0.042–0.074	0.008–0.014	0.088–0.099	0.021–0.030
(ii) *Remainder of Sapwood*					
Mean: All trees	8	0.045	0.007	0.057	0.033
Range: Dominant	1	0.040	0.006	0.053	0.027
Suppressed	1	0.043	0.007	0.060	0.031
Co-dominants	6	0.040–0.054	0.005–0.008	0.039–0.085	0.028–0.038
(iii) *Heartwood*					
Mean: All trees	8	0.045	0.002	0.044	0.042
Range: Dominant	1	0.048	0.002	0.054	0.034
Suppressed	1	0.052	0.003	0.049	0.035
Co-dominants	6	0.039–0.046	0.001–0.003	0.034–0.062	0.037–0.055
C. INTERNODE LEVELS					
Butt Discs					
Mean	4	0.052	0.006	0.063	0.031
Range		0.051–0.054	0.005–0.007	0.044–0.073	0.025–0.038
5th Internode					
Mean	4	0.046	0.005	0.051	0.036
Range		0.044–0.050	0.004–0.006	0.036–0.075	0.034–0.039
10th Internode					
Mean	4	0.054	0.007	0.064	0.036
Range		0.049–0.062	0.005–0.009	0.046–0.095	0.033–0.039
15th Internode					
Mean	4	0.070	0.013	0.098	0.034
Range		0.061–0.090	0.008–0.015	0.087–0.117	0.030–0.041
20th Internode					
Mean	4	0.091	0.014	0.122	0.029
Range		0.078–0.101	0.010–0.016	0.083–0.190	0.023–0.034

APPENDIX I—*continued*

	No. of Trees	% Oven-dry Sample N	P	K	Ca
D. SAPWOOD & HEARTWOOD FOR INTERNODE LEVELS					
(i) *Outer 6 rings Sapwood*					
Butt Disc					
Mean	4	0.064	0.011	0.090	0.021
Range		0.058–0.074	0.006–0.016	0.049–0.115	0.016–0.024
5th Internode					
Mean	4	0.056	0.009	0.074	0.025
Range		0.054–0.058	0.007–0.010	0.069–0.078	0.020–0.030
10th Internode					
Mean	4	0.060	0.010	0.077	0.028
Range		0.055–0.065	0.007–0.014	0.068–0.089	0.024–0.032
15th Internode					
Mean	4	0.072	0.015	0.113	0.029
Range		0.065–0.089	0.010–0.018	0.108–0.120	0.024–0.033
20th Internode					
Mean	4	0.091	0.014	0.120	0.028
Range		0.076–0.101	0.010–0.016	0.083–0.190	0.023–0.033
(ii) *Remainder of Sapwood*					
Butt Disc					
Mean	4	0.050	0.007	0.058	0.030
Range		0.045–0.052	0.005–0.008	0.044–0.073	0.018–0.036
5th Internode					
Mean	4	0.042	0.005	0.044	0.038
Range		0.038–0.047	0.003–0.007	0.014–0.084	0.033–0.043
10th Internode					
Mean	4	0.053	0.007	0.036	0.042
Range		0.046–0.066	0.005–0.010	0.020–0.055	0.040–0.044
15th Internode					
Mean	2	0.050	0.009	0.074	0.038
Range		0.050–0.051	0.008–0.009	0.067–0.080	0.021–0.047
(iii) *Heartwood*					
Butt Disc					
Mean	4	0.045	0.001	0.048	0.050
Range		0.040–0.048	0.001–0.001	0.032–0.060	0.041–0.061
5th Internode					
Mean	4	0.042	0.001	0.039	0.047
Range		0.039–0.047	0.001–0.002	0.022–0.069	0.041–0.062
10th Internode					
Mean	4	0.044	0.002	0.036	0.047
Range		0.040–0.047	0.001–0.003	0.025–0.050	0.038–0.057
15th Internode					
Mean	4	0.070	0.006	0.042	0.042
Range		0.054–0.108	0.003–0.008	0.035–0.047	0.034–0.061

POLARISATION MEASUREMENTS ON STEAM BORE CASINGS AT WAIRAKEI, NEW ZEALAND

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Summary

Estimates of the rate of corrosion of the casings of geothermal steam bores at Wairakei, New Zealand, were made from polarisation tests. These tests indicated a very high rate of corrosion but examination of one bore casing did not confirm this. It is suggested that where depolarisation is rapid, closer approximations to the observed rate of corrosion can be made by using potentials measured while the polarising current is flowing.

Introduction

Since 1950, drilling for steam has been carried out with considerable success at Wairakei by Ministry of Works, on behalf of New Zealand Electricity Department. About 75 bores are producing considerable quantities of steam, some of which is already being used for the generation of electricity. For this reason there is considerable interest in the life of the steel bore casing. The production area at Wairakei, situated on the volcanic plateau in the middle of the North Island, New Zealand, is about 3 miles long and 1 mile wide near the Waikato River. The area is covered by the debris of many ash showers. About a hundred feet of loosely consolidated pumice and rhyolite fragments overlie pumice beds and fresh water sediments derived from pumice, which in turn overlie ignimbrites. The production of steam at Wairakei has been described by Grange (1955).

Tests with steel plates buried at 3 ft have shown that the Wairakei pumice soil is only moderately corrosive to steel in non-thermal areas (Penhale, 1958). No tests on buried steel have been carried out in thermal areas. When aerated, the bore water is, however, very corrosive to many materials (Marshall, 1957), and considerable corrosion has also been observed on the steel casing of bores for steam and hot water at Rotorua, generally between the surface and the ground water level. Severe external corrosion of bore casings at Wairakei therefore seemed likely. Steam bores at Wairakei at the time of investigation were of two types, exploration and production, differing mainly in size and depth. Bores consisted of several concentric casings, the innermost being the deepest. The outermost or dummy casing was not connected to the inner casings and extended only from 20 to 60 ft down. The anchor casing, 10 in. to 6 in. in diameter, and the production casing, 8 in. to 4 in. in diameter were bolted together at the well head flange, the valve gear and steam lines being connected to this flange. All casings were cemented into the ground.

Protection of the outside of bore casing carrying hot water and steam is difficult. Coal tar coatings would melt or become very soft at the temperatures encountered (up to 250°C) thus rendering them very vulnerable to mechani-

cal damage, and preventing the grout from holding the anchor casing firmly in the ground. Cathodic protection, the application of negative potentials to limit corrosion, seemed the only possibility and it was decided to investigate this.

Corrosion is an electrochemical process, the most important reaction in the rusting of iron being its oxidation to ferrous ions.

$$Fe \rightarrow Fe^{2+} + 2e^-$$

This reaction will soon cease if there is no means of removing the excess electrons, which tend to polarise the surface of the metal. The most common depolarising reaction is the reduction of oxygen and water to form hydroxyl ions

$$2H_2O + O_2 + 4e^- \rightarrow 4OH^-$$

The hydroxyl ions then combine with the ferrous ions to form ferrous hydroxide which may oxidise further, forming hydrated ferric oxides (rust). Another depolarising reaction involving hydrogen sulphide is

$$H_2S + 2e^- \rightarrow S^{2-} + H_2$$

The regions where the electrons are produced become the anodes, and the regions where they are absorbed the cathodes of a large number of small electric cells, the amount of iron dissolving at the anodes being directly related to the current flowing in these cells. It is possible to alter the polarisation of the metal surface by applying current from an external source. Cathodic protection is achieved by applying sufficient negative potential to limit depolarisation.

Three criteria have been used for determining the current required for cathodic protection of steel (Sudrabin and Ringer, 1957).

(a) Polarise the metal surface to the potential given by the apparent break in potential vs current curves.

(b) Lower the initial potential by 0·3 volts.

(c) Maintain the structure at —0·85 volts to a copper/copper sulphate electrode placed in the ground.

Plots of the potential of the metal surface against the applied current are known as polarisation curves. These polarisation curves may show marked changes in slope, or "breaks" when the metal surface is polarised to the open circuit potential of the local anodes or cathodes. When the metal is polarised to the open circuit potential of the local anodes, then the anodic reaction, the solution of iron, is prevented and corrosion ceases. The current at which protection occurs depends on a number of factors, the most important being the rate of supply of oxygen or other depolarisers to the metal surface. It is possible to calculate from the polarisation curves the amount of current flowing in the local action cells and thus estimate the amount of corrosion (Schwerdtfeger and McDorman, 1952). These methods are usually considered to have the best theoretical basis, though this has been questioned by Stearn and Geary (1957). The determination of

the rate of corrosion and the amount of current required for protection depend on the presence of "breaks" in the polarisation curves. In high resistance soils, or with deep wells, the graphs of applied current against potential of well head to earth consist of two straight portions joined by a smooth curve (Haycock, 1957).

It is found that with steel under normal conditions, polarisation to a potential of — 0·85 volts with respect to a copper/copper sulphate electrode is sufficient for protection. Laboratory experiments show that in many cases this potential is very close to the potential at the cathodic break. Ewing (1955) has shown that the effect of sulphides is to increase the potential needed for protection, but as the concentration of hydrogen sulphide in the ground water at Wairakei is low near the surface (less than 1 part per million) this effect is probably negligible. The effect of temperature is more important as it can be calculated that at 200°C the potential necessary for cathodic protection would be increased to about — 0·9 volts.

A polarisation curve would enable cathodic protection currents to be estimated using any of the usually accepted criteria given above.

METHODS

Measurements of polarisation were made with the polarising current flowing and then immediately after it was interrupted, the difference between these two readings being due to voltages developed over resistances in the soil and on the surface of the bore. Because of the comparatively high soil resistivities (see Table 1) the voltage drop in the soil is high and hence the potential after interruption should give a truer picture of the polarisation of the bore.

A diagram of the apparatus is shown in Fig. 1. The current was supplied by a battery of accumulators and controlled by a variable resistance so that the current could be varied from 0·02 to 90 amperes. Potential measurements were made with a vacuum tube voltmeter (a Beckmann model G pH meter) using either a copper/copper sulphate or a calomel reference electrode placed 300 ft from the bore on the opposite side to the ground bed, which was commonly a nearby ground-water sample hole of 3 in. galvanised iron pipe. All connections were made with battery clips to the lowest flange of the bore and the potential lead was, if possible, connected below the current lead to eliminate any voltages arising from resistances in the flanges.

The measurements were made in the following order:

(i) Measure open circuit potential of bore.

(ii) Apply current for three minutes.

(iii) Measure potential of bore with current flowing.

(iv) Interrupt current and measure potential of bore as soon as possible.

(v) Apply an increased current for three minutes and read potential again.

(vi) Interrupt, etc.

TABLE 1—Polarisation Tests on Steam Bore Casings

Bore No.	Polarisability With Current (mV/A)		Protective Current Based on Current (amp.)		Ratio of Protective Currents (b)/(a)	Cased Depth of Bore (ft)	Inner Casing Diameter (in.)	Area of Casing Exposed to Soil (sq. ft.)	Protective Current Density Based on Current mA/sq. ft.		Soil Resistivity (ohm-cm)	
	Flowing	Interrupted	Flowing (a)	Interrupted (b)					Flowing	Interrupted	0–50 ft	0–1,500 ft
4/0	420	28	0.9	13	14	80	3.5	73	12	178		
4/1	41	12	5	25	5	954	6	2,050	2.4	12	4,100	1,700
4/2	180	86	1.6	3.3	2	954	6	1,950	0.8	2		
10	970	280	0.3	0.8	3	972	4	1,120	0.3	0.7	16,000	2,200
16	230	60	0.8	2.8	4	678	6	1,250	1.0	2	7,300	4,400
16/1	490	85	0.4	2.3	6	668	4	840	0.5	2.7		
18	11	1.4	22	260	12	1,477	8.6	3,610	6.1	71	3,400	2,500
19	11	0.9	34	420	12	2,202	8.6	5,300	6.4	79	.....	.....
20	25	1.7	10	220	22	1,383	8.6	3,290	3.0	67	2,500	500
22	24	3.8	7	37	5	1,595	8.6	3,980	1.7	9.2	.....	.....
24	27	5.4	12	49	4	1,133	8.6	2,790	4.1	18	.....	830
25	20	2.8	10	70	7	1,359	8.6	3,280	2.9	21	.....	1,200
27	20	2.9	11	70	6	1,400	8.6	3,530	3.2	20	.....	.....
28	35	2.9	6.7	77	11	1,453	6	3,130	2.1	25	.....	.....
29	13	2.3	12	63	5	1,230	8.6	3,140	4.0	20	.....	.....
31	15	3.2	0.7	3	4	1,000	8.6	2,610	0.3	1.1	.....	.....
37	31	4.2	6.6	50	8	1,081	8.6	2,670	2.5	19	.....	.....
38	33	5.7	4.9	27	5.5	986	8.6	2,460	2.0	11	.....	.....
39	37	5.6	3.8	24	6	989	8.6	2,460	1.5	9.7	.....	.....
40	34	8.3	6.3	25	4	1,001	8.6	2,630	2.4	9.7	.....	.....
43	17	3.8	9	36	4	992	8.6	2,600	3.4	13	.....	.....
44	11	2.0	12	63	5	1,751	8.6	4,310	2.8	15	.....	.....

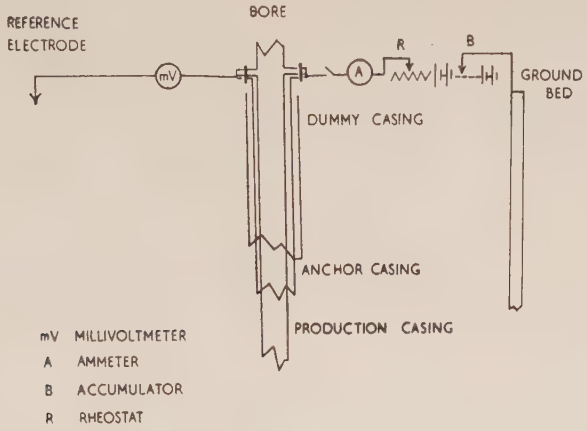

FIG. 1—Circuit diagram for polarisation measurements.

RESULTS

The results were plotted and in nearly every case the "current flowing" and "current interrupted" potentials showed a linear relation to the applied current except that at high currents the interrupted potential tended to drift rapidly because of depolarisation, making reliable measurements extremely difficult to obtain. The critical time factor in these measurements has been noted by Barrett and Gould (1956). The "current flowing" curves usually fell outside the range of the potentiometer (1.3V) after a few measurements. Polarisation curves of three typical bores, Nos. 4/1, 4/2, and 20, are given in Figs. 2, 3, and 4.

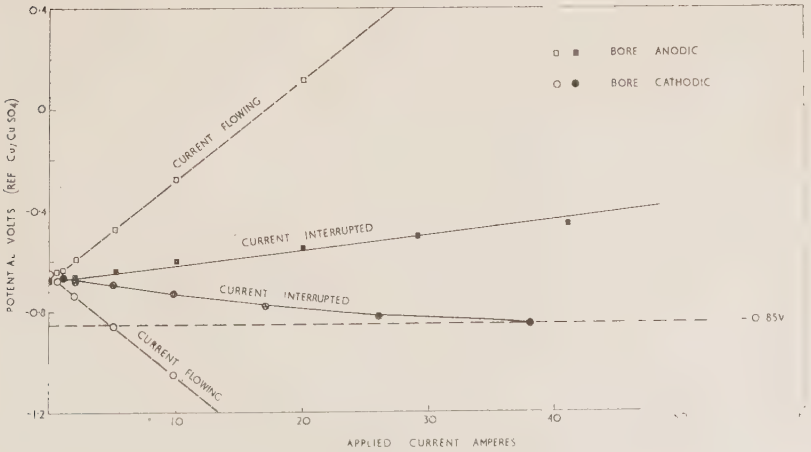

FIG. 2—Polarisation curves for Bore 4/1.

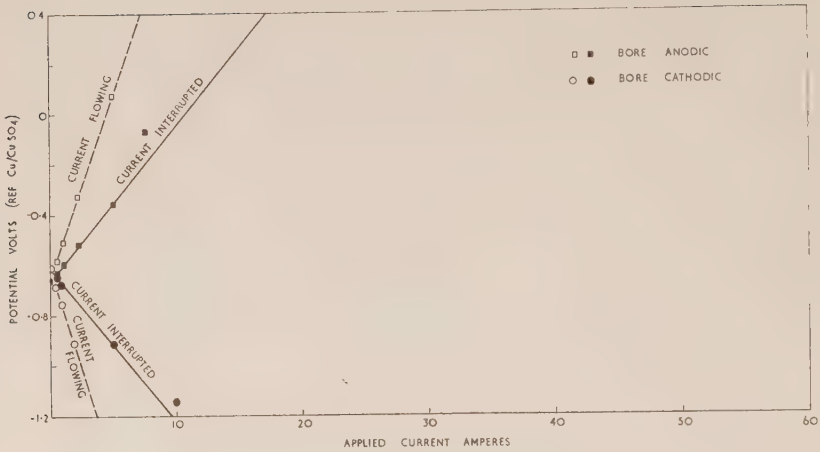

FIG. 3—Polarisation curves for Bore 4/2.

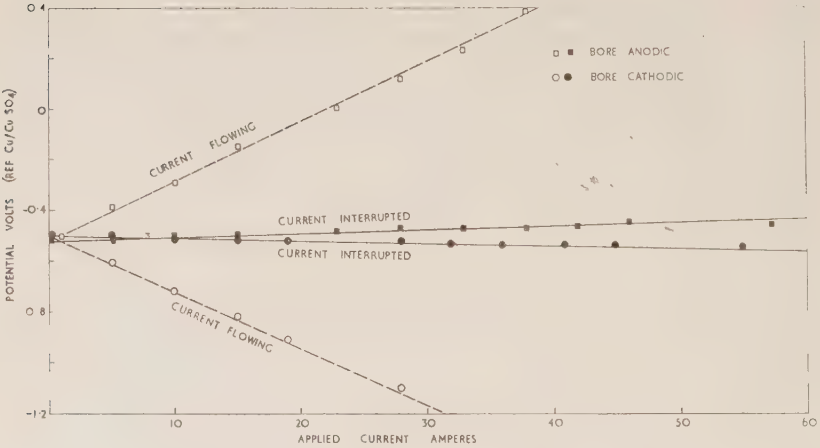

FIG. 4—Polarisation curves for Bore 20.

The linear relation between "interrupted" potential and applied current can be expressed in millivolts/ampere and termed the polarisability of the bore, this being the change in potential of the bore caused by a change in applied current of one ampere. Polarisabilities of the bores and other figures calculated from the results are listed in Table 1. The slopes of the anodic and cathodic curves are similar (see Figs. 2, 3, and 4).

The small exploration bores with 4 in. or 6 in. production casing and cased depths of less than 1,000 ft polarised readily, most falling in the range 40–400 mV/A with current still flowing, and 10–100 mV/A with

current interrupted (e.g. 4/1, 4/2, Figs. 2 and 3). The much larger production bores with $8\frac{5}{8}$ in. casing to a depth of about 1,500 ft polarised only with difficulty (10–40 mV/A current flowing, 1–8 mV/A current interrupted) (e.g. Bore 20, Fig. 4).

This division into two groups depends on size. Reference to the protective current densities shows that most of the bores fall in the range 9–25 mA/sq. ft if the potential at interruption is used in the calculation and 1–4 mA/sq. ft if the potential with current still flowing is used. Figures ranging from 0·3–60 mA/sq. ft. have been quoted in the literature (Sudrabin, 1945), In surface soils 3 mA/sq. ft is a common figure.

The difference between "current flowing" and "current interrupted" potentials is directly related to the current and thus may be represented by a resistance. This resistance may be the resistance of the soil close to the bore or it may be that of the bore or that contributed by the flanges and joints. This total resistance has been calculated for each bore and varies from 1·0 to 8×10^{-3} ohms for all production bores, and from 8 to 500×10^{-3} ohms for the exploration bores. For comparison, the resistance of 100 ft of $8\frac{5}{8}$ in. bore casing (30 lb/ft) is about $0{\cdot}006 \times 10^{-3}$ ohms.

Reproducibility

Repeat measurements were made on 15 of the 22 bores tested after a period of 6 to 12 months. Agreement varied widely from extremely good to $\pm$ 75%. The average variation between replicates was $\pm$ 25%. Some of the variations are probably real and caused by differences in ground-water level and oxygen availability at different times of the year. The differences could not be considered significant without taking many more readings.

Ground Beds

To avoid putting in temporary ground beds for test purposes, the ground-water sampling holes were used wherever possible. These sampling holes consisted of 80–100 ft of 3 in. galvanised pipe. Ewing and Bayhi (1948) had noted that variations in the position of ground beds had little effect. A check was made, however, to see that this applied at Wairakei.

Polarisation measurements using ground-water hole 4/0 and E, another nearby ground-water hole as ground beds for bores 4/1 and 4/2 showed no difference although the ground beds are 90 ft apart, 4/0 being between 4/1 and 4/2, and E well away from these bores. Similar measurements made on bore 16, using bores 16/1 and 16/0 as ground beds, also showed very little difference. Relative distances, depths, surface areas, and polarisabilities are as given in Table 2.

At bore 19 the ground-water hole could not be used and a water main on the surface was used instead. This gave similar results to those given by other bores when using ground-water holes as ground beds. Thus, considerable variation in ground beds made very little difference to the polarisation of the bore and ground-water holes are suitable for test purposes.

TABLE 2

	Ground Water Hole 16/0	Bore Hole 16/1
Distance from bore 16 (ft)	63	9
Depth (ft)	120	680
Area (sq. ft)	94	826
Polarisability of bore 16 (mV/A)	56	57

Various positions of the reference electrode were tried at two of the bores. At bore 20 the following electrode positions were tried: (Fig. 5).

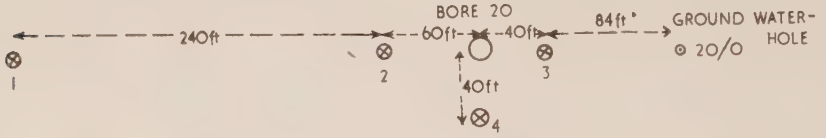

FIG. 5—Electrode positions around Bore 20.

(1) 300 ft from the bore on the side opposite to the ground bed.

(2) 60 ft from the bore on a line joining the bore and ground bed on the side opposite to the ground bed.

(3) 40 ft from the bore between it and the ground bed.

(4) 40 ft from the bore at right angles to the line joining the bore and the ground bed.

The "current interrupted" curves were independent of electrode position, but the "current flowing" curves showed slight differences in that slightly more voltage was found with the electrodes nearer the ground bed.

At bore 4/2 the electrode was placed in two positions:

(1) 300 ft from the bore on the opposite side to the ground bed.

(2) 1 ft 6 in. from the outer casing of the bore on the opposite side to the ground bed.

This bore polarised readily and took a long time to return to its original potential. However, the "current flowing" curves were only slightly different in slope and the "current interrupted" curves were practically parallel. Logan (1954), quoting Pearson, states that the length of pipe scanned by an electrode is four times the separation of the electrode from a horizontal pipe. With a vertical bore an electrode at the surface would scan to a depth of twice the separation. For this reason the electrode was placed as far as possible from the bore, even though variations in electrode position caused no observed changes in polarisation.

Because the slopes of the "current flowing" curves are virtually independent of the reference electrode position, it would seem that the major part of the current flow is below the surface and possibly below the level of the dummy casing. It is probable that little current flows in the dry surface

soil above the water table. This was confirmed by measurements made on a water main lying on the surface near bore 16, using water hole 16/0 as a ground bed. In this instance the voltages recorded varied considerably with electrode position, indicating that when the current was forced to flow near the surface the voltage developed over the soil resistance was added to the pipe to soil potential as measured by the reference electrodes.

The Application of Cathodic Protection

The current required for cathodic protection can be shown to be the current necessary to polarise the surface of the metal to the open circuit potential of the local anodes. This is usually indicated on the cathodic polarisation curve by a change in slope. However, no such changes in slope or breaks were observed in any of the curves. It is quite possible that such breaks, if they occurred within the ranges measured, were concealed by the rapid drift in potential occurring when the current was interrupted.

The anodic and cathodic polarisabilities are in every case almost the same, so that if the breaks are assumed to occur at or near the currents indicated by a potential of — 0·85 volts for the cathodic curve, then it is possible to estimate roughly the corrosion current (Schwerdtfeger and McDorman, 1952). This corrosion current is of the same order as the current required for protection. A current of about 200 amperes, such as is required by bores 18 and 20 if the potential at interruption is used, corresponds to a loss of about 4,000 lb of steel annually, a very much higher figure than those published for bore casings of oil wells in various parts of the world.

The high currents and hence implied high corrosion found in the present work could be the result of such factors as high temperature, loosely consolidated ground allowing oxygen to percolate to considerable depths, and oxygen concentration cells between top and bottom of the bores. It was therefore decided to check this interpretation by removing a bore casing as the high currents indicated might equally well be due to faulty method or interpretation. For various reasons it was not possible to remove a typical steam bore casing but it is very probable that the conclusions obtained from the water sample hole 4/0 will apply to steam bores.

The casing of the ground water sampling hole 4/0 was removed on 15 April 1957 after being in the ground for about 4½ years. Selected sections were cleaned and weighed. The weight loss of the entire 80 ft of casing was estimated from these figures. Results are shown in Table 3.

The actual weight loss estimated from the recovered casing is only $^1/_{25}$ of that calculated from the protective current (based on the potentials after interruption). If the potentials with the current flowing are used agreement is much closer, the actual weight loss being nearly 0·6 of the loss calculated from the protective current. The protective current of 12 mA/sq. ft., though high, is not excessively so. The average rate of penetration is 0·035 mm/yr, a moderate value.

TABLE 3

Water Sampling Hole 4/0

Depth 80 ft — Casing 3½ in. steam pipe

Installed September 1952 — Removed April 1957

Area exposed to soil: 73 sq. ft

	kg
Actual weight loss estimated by weighing corroded specimens	22

Protective Current	Amps.	mA/ sq. ft	Corresponding Weight Loss Calculated From Faraday's Law
Based on potential at interruption	13	180	540
Based on potential with current flowing	0.9	12	38

Reference to Table 1 shows that the ratio of the protective currents calculated from the potentials with current flowing and current interrupted vary widely, the greatest differences between the two methods occur with the larger bores where depolarisation is very rapid and the potential readings are more likely to be low and inaccurate.

CONCLUSIONS

Tests on one shallow bore at Wairakei suggest that polarisation tests using the potential immediately after interrupting the polarising current (the usually accepted method) grossly overestimated the corrosion occurring. This overestimate of the corrosion is due partly to the rapid depolarisation of steel at Wairakei and partly to the rather sluggish response of the simple equipment used for measurement. Better agreement between actual corrosion and that calculated from these measurements is obtained if the potentials to ground, obtained with the polarisation current still flowing, are used to calculate the corrosion current. These potentials include an extra voltage developed across the soil resistance and other resistances in the circuit and should result in an underestimate of the corrosion rate. From the results obtained on bore 4/0 it appears that the corrosion so calculated is of the same order as that estimated by weighing sections of corroded pipe and it would appear that for polarisation tests of this type the uninterrupted current method gives reasonable results.

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TOXICITY OF PENTACHLOROPHENOL TO THE COMMON HOUSE BORER *ANOBIUM PUNCTATUM* DE GEER

II. A TRIAL OF EFFECTIVENESS, 1951–1960

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(Received for publication, 14 April 1960)

Summary

Six concentrations of pentachlorophenol, 5.0; 3.5; 2.0; 1.0; 0.5 and 0.2 per cent. in power kerosene were used for dip treatment of sapwood blocks of kahikatea, *Podocarpus dacrydioides*. The treated blocks were caged individually and numbers of *Anobium* beetles added year by year. In all treatments some blocks became infected during the first year when the four lower concentrations failed completely. Although the highest concentration gave some control for eight years, pentachlorophenol cannot be considered very effective against *Anobium*. It is concluded that the use of pentachlorophenol for *Anobium* control should be discontinued.

INTRODUCTION

In the first part of this paper (Spiller 1948a) it was emphasised that three factors may be considered in discussion of the value of pentachlorophenol for control of *Anobium* infestations: residual contact effect, ovicidal effect, and persistence or permanence. Results in that paper established that pentachlorophenol has a residual contact effect and that it is also ovicidal. In neither of these effects is pentachlorophenol an outstanding insecticide, but this combination of separate effects did result in excellent control being obtained with dosages of only a few per cent pentachlorophenol. However, it was also shown that there was considerable loss of effectiveness after one year, the loss being proportional to the amount of pentachlorophenol used in the initial treatment.

Following this, extensive insectary tests showed that single brush coats of pentachlorophenol in power kerosene did not prevent emergence of *Anobium* beetles (Spiller 1952). However, the earlier results (Spiller 1948a) implied that the pentachlorophenol would kill many of the beetles before many eggs were laid, and that most of the eggs would succumb to the ovicidal effects. The early results also implied that effectiveness would decrease with time but gave little indication of how long pentachlorophenol would remain effective when used for the control of *Anobium* in buildings.

Therefore it was considered desirable to make a more direct test of the effectiveness of pentachlorophenol against *Anobium* using test procedures and conditions which match field conditions. The results of this trial are presented and discussed in this paper.

MATERIALS AND METHODS

Test Procedure

The test was carried out in a gauze wall insectary. Sapwood blocks of sufficient size to support a considerable number of *Anobium* for a full life cycle were dipped in the appropriate solutions some two months before the flight period. These blocks were housed individually in ventilated tins and infested with a considerable number of *Anobium* beetles year by year. A treatment was considered to have failed when beetles emerged from one or more of the test blocks.

Blocks

Test blocks, measuring 6 in. long × 2 in. wide × 0·75 in. thick, were cut from eight large boards of sapwood kahikatea (*Podocarpus dacrydioides* A. Rich.), the blocks from each being kept separate and labelled with the code letter of their parent board. Blocks were kept in a conditioning room at 22·5°C and 75% R.H. until required for treatment.

TREATING METHODS

Blocks were treated early in October 1951. Each treatment was applied to eight blocks, one block from each board. Each block was weighed to give an air-dry weight, placed with the seven other blocks in a wirework dipping rack (which was designed to prevent blocks touching each other), immersed in the appropriate solution for 30 min, removed, drained in the rack on a drip tray for 30 min, drained on wires on paper for a further 50 min, and then weighed. After weighing, blocks were placed on wire racks in an insectary until infested during December 1951 – January 1952.

Testing Methods

Blocks were caged individually in two-pound round paint tins with double tight lids. Ventilation was provided by an inverted Type IV cage (Spiller 1948b) which was press fitted into a round hole punched in the centre of the tin lid. The Type IV cage was readily removed without removing the lid of the tin and the centre hole of the lid then provided a very convenient port for introducing test beetles.

It was intended that each block should be infested at each flight but in some years there were insufficient beetles and on two occasions all available beetles were diverted to another purpose. The number of beetles introduced into each tin in each year was never small and was often large, sometimes several hundreds, and it can reasonably be assumed that each set of beetles represented at least a hundred eggs per block. Inspection has repeatedly shown that several hundred eggs were deposited in many of the blocks. Actual infestations were as follows: All blocks 1951–2, 1955–6, 1956–7, 1958–9 and 1959–60; three boards (A, D, F) in 1953–4 and three different boards (B, C, G) in 1954–5; no beetles were added in the 1952–3 and 1957–8 flights.

Each year all blocks were examined and those showing exit holes recorded and withdrawn. From February 1952 until November 1953 lids were removed from the tins, the open tins with blocks inside being stored in a ventilated loft. For the remainder of the test, lids were not removed except to examine blocks; and tins were stored in a single layer on shelves in the insectary.

TREATMENTS

Pentachlorophenol was used at the six concentrations: 5·0, 3·5, 2·0, 1·0, 0·5, and 0·2% w/w in power kerosene. Diacetone, 1% w/w, was added at the highest concentration to effect solution. When allowance was made for the different amounts of solution retained, these concentrations gave average values of 1·40; 0·95; 0·58; 0·27; 0·12 and 0·06 grams pentachlorophenol per square foot.

Six sets of untreated controls and two sets of kerosene-treated control blocks were included.

RESULTS

Results are shown in Table 1, where blocks are scored in four categories, 0, indicating that no beetles have emerged; x emergence during 1954–5 or 1955–6 flights; † emergence during 1956–7 or 1957–8 flights; ‡ emergence in subsequent flights. Dissection of the nine blocks (4 control, 5 treated) without exit holes, entered in Table 1, disclosed that each of the four control blocks was or had been infested, the larval tunnels in some blocks being both numerous and large. No larval tunnels were found in any of the five treated blocks.

DISCUSSION

Blocks were first exposed to infestation during the 1951–2 flight but were not exposed during the 1952–3 flight. Hence, those beetles which emerged during the 1954–5 and 1955–6 flights must have developed from eggs laid not much more than three months after the blocks were treated. With seven of the eight boards in the test the four lowest concentrations (0·2, 0·5, 1·0 and 2·0% pentachlorophenol) became infested at this initial infestation. In two boards, A and B, infestation also occurred at the 3·5% concentration and in one board, A, infestation was achieved at the highest concentration, 5·0%. Thus at the initial infestation all treatments failed in one or other of the boards. However, the two higher concentrations were giving considerable control, as each of their three failures involved only one emergence per block, this contrasting with numerous emergences from some of the other treatments and the control blocks.

Beetles emerging during the 1956–7 or 1957–8 flights originated as eggs laid during or prior to the 1954–5 flight, that is, during the initial infestation and the 1953–4 flight for boards A, D, and F, or the initial infestation and the 1954–5 flights for boards B, C, and G. As neither E nor H was reinfested at these times the emergence of adults from the 0·5% treatment

of board H clearly indicates a prolonged larval development from the first infestation of 1951–2. This is confirmed by a parallel emergence from one of the kerosene-treated controls. During this period failure occurred in the four exposed blocks of the 3·5% treatments and in two (B and F) of the six exposed blocks at the highest concentration. These failures originated from eggs laid at either 2·3 or 3·3 years after treatment.

TABLE 1—Results Obtained by Repeated Infestation of Pentachlorophenol-treated Blocks with *Anobium punctatum*. Blocks Treated October 1951, First Infested December 1951 – January 1952

Concentration of Pentachlorophenol		Code Letter of Board							
Percent. w/w in Power Kerosene	Grams sq. ft.	A	B	C	D	E	F	G	H
5·0	1.40	x	†	‡	0	0	†	0	0
3·5	0.95	x	x	†	†	‡	†	†	0
2·0	0.58	x	x	x	x	x	x	x	‡
1·0	0.27	x	x	x	x	x	x	x	‡
0·5	0.12	x	x	x	x	x	x	x	†
0·2	0.06	x	x	x	x	x	x	x	x
	Power Kerosene	x	x	x	x	0	x	x	†
		x	x	x	x	0	x	x	0
Controls	Untreated	x	x	x	x	x	x	x	x
		x	x	x	x	x	x	x	x
		x	x	x	x	x	x	x	x
		x	x	x	x	x	x	x	‡
		x	x	x	x	x	x	x	‡
		x	x	x	x	x	x	x	0

0 No exit holes February 1960.

x Beetles emerged during 1954–5 or 1955–6 flight.

† Beetles emerged during 1956–7 or 1957–8 flight.

‡ Beetles emerged subsequent to the 1957–8 flight.

Beetles which emerged subsequent to the 1957–8 flight all seem to have originated from beetles introduced during 1955–6 or 1956–7, rather than as late emergences from early exposures. Blocks E and H were not exposed to infestation between the initial flight of 1951–2 and the flight of 1955–6; the only other block in this category being the 5·0% concentration of board C, a board which had had normal three-year emergences throughout.

Board E and board H proved difficult to infest, only a few beetles emerging even in the untreated controls. With board H in particular, failure to infest blocks treated with the higher concentrations must be discounted, for two of the untreated pieces were still without exit holes seven years after the experiment commenced. Lack of emergence from the two power kerosene treated controls of board E is quite inexplicable, but these hardly affect the results.

This test has shown quite clearly that petachlorophenol treatments cannot give adequate protection against infestation by *Anobium*. At each concentration one or more blocks became infested at the first exposure some two to three months after treatment; the two highest concentrations gave considerable control, but the four lowest concentrations failed completely. For the 3·5% concentration this control had vanished at the next exposure 2·3 years after treatment. The highest concentration was still effective on some blocks when the experiment terminated eight years after the blocks were treated, but obviously pentachlorophenol is not particularly effective against *Anobium*.

CONCLUSION

Pentachlorophenol is not a suitable material for *Anobium* control. It is neither permanent nor particularly effective; it does not prevent beetle emergence, and treated timber is readily infested.

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A STUDY ON CONTROL OF INFESTATIONS OF THE COMMON HOUSE BORER *ANOBIUM PUNCTATUM* DE GEER

PART 2. A TEST OF DIESEL OIL AND FRACTIONS 1953–60

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(Received for publication, 14 March 1960)

Summary

A diesel oil was fractionated into three approximately equal portions. These and the parent oil were tested for control of infestation of the common house borer, *Anobium punctatum*. Oils were applied as single brush coats to infested boards, and beetle emergence followed for seven years. The light fractions gave good initial control but the treated boards soon became reinfested; the heavy fraction was ineffective initially, but thereafter gave perfect protection. These results indicate that diesel oil owes its effectiveness to a combination of properties and that no spectacular improvement in effectiveness could be achieved by moderate fractionation or refining.

The parent diesel oil gave effective control. The slight reinfestation that occurred is probably insufficient to maintain the *Anobium* population.

Introduction

In Part 1 of this paper (Spiller 1952) it was reported that single brush coats of diesel oil (gas oil) gave near perfect control of infestations of the common house borer (*Anobium punctatum* De Geer). It was considered that surface application of diesel oil was the treatment of choice for all situations where staining and a slight oiliness could be tolerated.

Experimental Technique

These disadvantages might be minimised by suitable procedures at the refinery, but before this could be considered it was necessary to know whether insecticidal efficacy resided in some particular cut or fraction of the diesel oil. Thus it might be possible to produce a light coloured or colourless oil especially suitable for control of *Anobium* infestations, a diminished oiliness of finished treatment being achieved by the use of less oil of enhanced insecticidal properties. Further, there was the problem of how long diesel oil treatments remain effective and whether the long lasting fractions (*see* Part I, Table 7) are also the insecticidal fractions.

Diesel oils have a very broad spectrum of properties with fractions ranging from kerosenes through light and heavy lubricating oils to petroleum jelly. They may contain paraffinic, naphthenic, and aromatic hydrocarbons in various proportions and a medley of minor constituents. Attempts at close fraction-

ation are major undertakings not warranted by the present purpose. A diesel oil* was therefore split in three broad and approximately equal fractions as follows:

Fraction A. B.P. 200°–260°C atmospheric

Fraction B. B.P. 145°–185°C at 33–4 mm Hg

Fraction C. Distillation was continued at 0·5 mm Hg until solid condensed in and blocked the condenser.

The residuum of wax and grease in the distilling flask was discarded.

Testing methods were essentially the same as those described in Part I, the only variation being the randomisation of test pieces amongst treatments and controls. This departure from the matched-half technique was possible because of the availability of specially suitable boards, infested for these tests as follows. During 1950 a number of 6 in. × 1 in. and 8½ in. × 1 in. boards of sapwood kahikatea (*Podocarpus dacrydioides* A. Rich.) were placed in an infestation room of the insectary. At the 1950–51, 1951–52, and 1952–53 flights, *Anobium* beetles were introduced, in large numbers during the first flight, and more moderate numbers on subsequent flights. The room was not opened until September 1953 when suitable boards were selected, labelled, and cut into 16 in. lengths. Six of these pieces comprised a set of boards for a treatment or control. When pieces were treated during September 1953, the number of exit holes on each piece was recorded and the holes marked or cancelled. Counting and marking has continued for each flight until the present time.

Four materials, the three fractions defined above, and the parent oil were tested. During September 1953 each oil was applied as a single brush coat to one set of boards. The amount of oil required varied considerably from piece to piece; average amounts were as follows:

diesel oil, 50 ml/sq. ft.; fraction A, 43 ml/sq. ft.; fraction B, 41 ml/sq. ft.; fraction C, 40 ml/sq. ft.;

an average of these values approximating to one gallon per 100 sq ft.

Two sets of six pieces and one set of three pieces were retained as controls.

After treatment all pieces were hung in open spacing on a rack in an insectary room. Places were allocated at random. The numerous beetles that emerged from this and other experiments at each flight remained in the room and provided ample opportunity for pieces to become reinfested and further infested.

Results, as total number of beetles emerging from each treatment or control in each year, are shown in Table 1.

DISCUSSION

Because large numbers of beetles emerged from the untreated boards, the results obtained from the treatments present no difficulties of interpretation.

*The oil used was purchased as "Shell Dieselene".

TABLE 1—Results, as Number of Beetles Emerging at Each Flight, Obtained by a Single Brush Coat of Diesel Oil or Diesel Oil Fractions on Boards Infested with *Anobium*. Boards Treated September 1953. Exit Holes Marked and Counted at Each Flight

FLIGHT*	Number of Beetles Emerging in Each Period						
	1953–4	1954–5	1955–6	1956–7	1957–8	1958–9	1959–60
	1	2	3	4	5	6	7
TREATMENT							
Gas oil	45	4	1	0	10	26	20
Fraction A	9	5	26	199	1,003	1,330	243
,, B	1	1	0	7	153	385	204
,, C	119	1	0	0	0	0	0
Control 1	169	1,076	3,654	1,724	381	94	56
,, 2	81	1,575	2,453	2,637	457	102	60
,, 3†	125	719	2,133	1,089	298	73	15

*In Auckland flights occur December–January.

†3 pieces only (all other six pieces).

For the first four flights after treatment the results obtained with diesel oil were essentially similar to those already reported (Part I, Tables 3 and 4) and complete or virtually complete control was achieved except in the flight following treatment. At the fifth, sixth, and seventh flights some beetles emerged, indicating that early reinfestation had occurred, the adults emerging at the fifth flight having developed from eggs laid during the second flight, some fifteen months after treatment. However, the number of beetles emerging in these latter years is relatively small (*cf.* fraction A) and there is not much doubt that the diesel oil treatment is still exercising a very considerable control even after more than six years.

The results obtained with fraction A might reasonably have been anticipated for a light fraction (*cf.* kerosene and mineral turpentine Part I, Tables 3 and 4). That reinfestation occurred at the first flight only three months after treatment and became marked in subsequent flights is revealed by the increased emergence at the fourth flight and the massive emergences at the fifth and sixth flights.

With fraction B excellent initial control was obtained and this was virtually complete in the two following years. The slight emergence at the fourth flight indicates very slight reinfestation during the flight following treatment. In the following years this reinfestation became marked but the treatment has not yet broken down as completely as has the fraction A treatment.

Fraction C has given perfect control throughout the test, except in the flight immediately following treatment, when by comparison with controls, this oil was possibly without effect on emergence.

Perhaps the most interesting aspect of these tests is the implication that the two requirements for effective borer control, namely good initial control and long lasting effectiveness are separate attributes in these oils. The light oils, especially fraction B, were highly effective initially, but lacked long-

lasting effectiveness, while the heavy fraction C appears to be very longlasting but almost ineffective initially. The problem of oiliness is not resolved: as was to be expected, oiliness increased with increasing boiling point. Initially, boards treated with fraction A were virtually non-oily, those treated with fraction B somewhat oily and comparable with the parent diesel oil, those treated with fraction C distinctly greasy. Six and a half years after these oils were applied, no oiliness could be detected on boards treated with fractions A and B or the parent oil, but the boards treated with fraction C felt slightly greasy, although this was not sufficiently marked to be unpleasant. Because of these differences in oil properties, it is unlikely that further fractionation could achieve an oil which combined good initial control with longlasting effectiveness, although this could probably be achieved by recombining fractions B and C. Thus the results indicate that diesel oil is effective for *Anobium* control because of its broad spectrum of properties and that no spectacular improvement could be achieved by moderate fractionation or refining.

The results have also shown that treatment with diesel oil does not confer protection against reinfestation, some beetles emerging as early as the fifth flight (4·3 years) after treatment. In assessing the importance of this information as it affects borer control in buildings, two points must be considered. First, reinfestation has occurred only because of the large number of beetles emerging into the room from untreated boards and unsuccessful treatments. Had the diesel oil treated boards been caged separately the five beetles that emerged during flights 2, 3, and 4 could not have caused significant reinfestation. Secondly the reinfestation is rather slight, 56 beetles having emerged during the fifth, sixth, and seventh flights, compared with 2576 from boards treated with fraction A. Thus the reinfestation amounts to only 2·2% of that in an unsuccessful treatment. Recent work by the author has shown that the average number of eggs laid by *Anobium* females does not exceed 55. If only 2·2% survive, then each female emerging after the diesel oil treatment would produce about 1·2 adult progeny, one half of which would be males. Hence, in this treatment, the slight reinfestation that has occurred is insufficient to maintain the *Anobium* population.

This suggests that when diesel oil is used on buildings for control of *Anobium* infestations, good control will be obtained for a number of years, during which reinfestation, if present, will be very slight and probably undetectable. But perhaps treatment may be necessary again, at or about the following decade.

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LARVAL SIMULIIDAE (DIPTERA) FROM NAVARINO ISLAND, TIERRA DEL FUEGO

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(Received for publication, 13 July 1960)

Summary

The previously undescribed larva of *Austrosimulium anthracinum* (Bigot) is described and the relationships of the species are discussed. A brief description is given of the larva of an undetermined species of *Gigantodax* which constitutes the southernmost record for the genus.

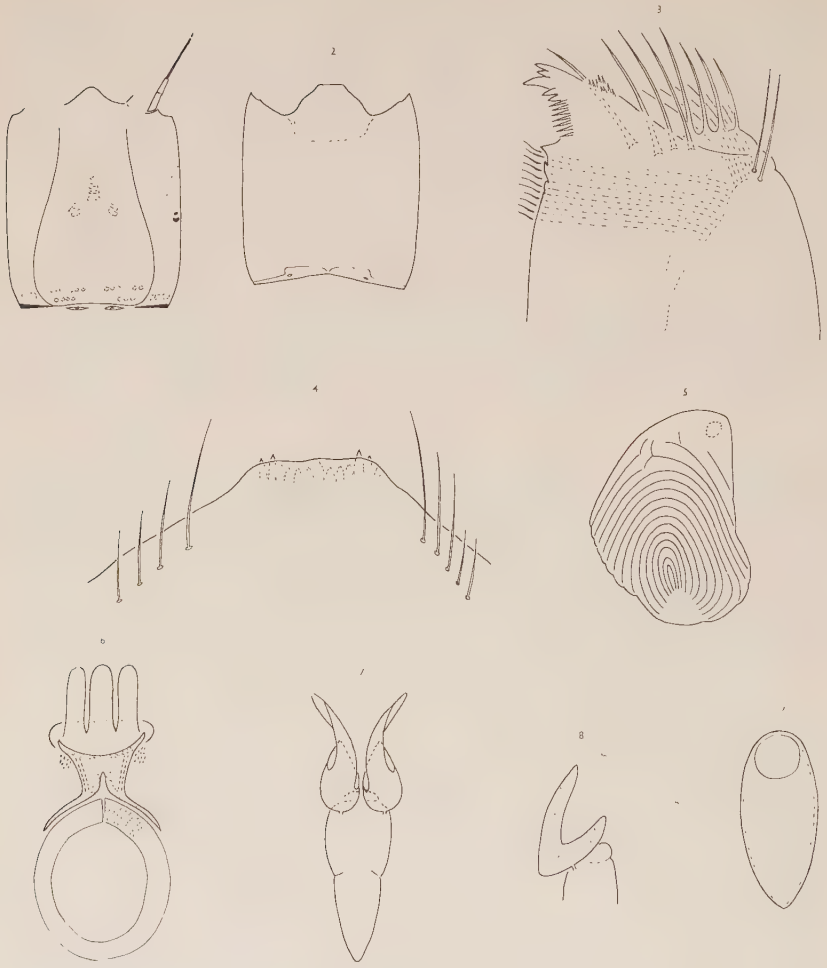
Introduction

A small collection of the immature stages of Simuliidae was made by Professor G. A. Knox, of Canterbury University, during the course of the Royal Society Expedition to Southern Chile, in 1958–59. The collection, though small, proved to be particularly interesting in connection with a current study of N.Z. Simuliidae, since it contained the previously unknown larva of the only reputed species of *Austrosimulium* occurring outside of Australia and New Zealand.

Austrosimulium anthracinum (Bigot)

Larva: Length 6 mm.

Head (Figs 1, 2); colour yellowish, with black posterior margins laterally and ventrally. Frontal pattern dark brown, consisting of a median longitudinal stripe interrupted at mid-length, the anterior part of five diminishing transverse elements, a submedian spot at mid-length on each side composed of two elements, and a transverse area posteriorly on each side. Ventral incisure absent; the posterior tentorial pit sub-circular; a dark brown pigmented area from each pit tapering towards the mid-ventral line but not meeting there. Frontal sclerite widest posteriorly with postero-lateral margins rounded; post-frontal processes of epicranium separated, or nearly so, from the epicranium, elongate-lanceolate, with dark spot at mid-length. Antenna with segments 1 & 2 dark, 3 & 4 pale; longer than basal piece of mouth brush, 1 plus 2 shorter than basal piece, 1 longer than 2, 1 plus 2 shorter than 3 plus 4. Mandible (Fig. 3) normal, setae of outer longitudinal brush, tapering, pointed; three internal marginal teeth, distal largest erect, two proximal teeth recumbent, directed distad. Mouth brush normal, basal piece half as long as rays; rays slender, hairs fine, biseriate. Submentum (Fig. 4) with 4 or 5 simple setae on each side, in ventral view all except 1 or 2 lateral teeth on each side concealed below anterior margin; 13 teeth, median tooth longer than the 3 adjoining teeth on each side, 4th or 5th tooth longest. Thoracic proleg normal. Gill spot (Fig. 5) somewhat pear-shaped, widest ventrally, long axis not vertical but inclined caudad ventrally,



Austrosimulium anthracinum

FIG. 1—Larva. Head, dorsal.
FIG. 2—Larva. Head, ventral.
FIG. 3—Larva. Mandible.
FIG. 4—Larva. Sub-mentum.
FIG. 5—Larva. Gill-spot.
FIG. 6—Larva. Anal sclerite.
FIG. 7 –Pupa. Breathing organ, dorsal.
FIG. 8—Pupa. Breathing organ, lateral.
FIG. 9—Cocoon.

pale-castaneous dorsally, dark brown in ventral half. Ventral half occupied by a series of about 10 regular concentric sub-oval lines, except for a pale triangular area on ventral margin. The dorsal and ventral lobes of the breathing organ lie one on top of the other, and the concentric ovals are produced by the telescoped pseudo-segments of the lobe. Abdomen, normally tapered, without *Cnephia*-form. Anal gills simple tri-lobed. Anal spines conical, not divided apically, grouped caudad of the anterior arm of the anal sclerite on each side. Anal sclerite (Fig. 6) X-shaped, the posterior arms extending nearly to the mid-pleural line, and with one or two short setae cephalad, the bases enclosing a narrow paler area which is without pigmented spots. Ring sclerite absent. Backward struts present, beneath the dorsal element connecting the anterior and posterior arms. Ventral tubercles present. Crotchet ring normal.

The larva is correlated with the pupa by the structure of the gill-spot.

PUPA: (Figs 7, 8). As described by Wygodzinsky (1953). The breathing organ is a thin, somewhat cupped lamella, composed of a longer dorsal, and a shorter ventral lobe, each with prominent pseudo-segmentation, and without filaments.

COCOON: (Fig. 9). Close-textured; definite elongate-oval in shape; with a circular aperture, and a definite but narrow collar bounding the aperture ventrally; complete in the posterior half ventrally.

MATERIAL EXAMINED: Two collections from a large stream (no. 7) to the East of Pt. Williams, Navarino Is., Tierra del Fuego. FWN 7·2, one pupa and cocoon together with pupae of *Edwardsina* sp. FWN 7·5, two gill-spot larvae.

COLLECTOR: G. A. Knox, 23/11/1958.

The type of the species is a female from Orange Bay, Tierra del Fuego. The most northern occurrences are at Angol (Chile) and in the Bariloche area. Wygodzinsky redescribed the female and gave the first description of the pupa, which he correlated with the female, and of the cocoon.

He considered *A. moorei* (Silva Figueroa) the type of which was from Taitao Peninsula, to be a synonym of *anthracinum*. Edwards (1931) with only the female at his disposal, placed the species in *Austrosimulium*, presumably because of the ten-segmented antenna and the curved Cu vein. The female, as Wygodzinsky noted, differs from *Austrosimulium* in the presence of spiniform setae in the distal part of the R_1 vein – a character which is present in *Cnephia*, *Simulium* and some *Gigantodax* species. The breathing organ of the pupa is quite unlike that of all other species of *Austrosimulium*, but suggests affinity with *Simulium* (s.g. *Hearlea*). The rows of basal spines on the abdominal tergites are characteristic of *Cnephia*, *Gigantodax* and *Simulium* and not of *Austrosimulium*. The small terminal hooks are similar to those of *Simulium* and *Austrosimulium*, as is the close textured cocoon of definite shape. The presence of backward struts in the anal sclerite of the larva suggests either *Austrosimulium* or *Gigantodax*, but these struts are also present in *Simulium oviceps* Edwards, and are figured in two other *Simulium* species from Africa. The absence of the ring sclerite, and the presence of

ventral tubercles, is characteristic of the Australian "*furiosum* group" of *Austrosimulium,* but in this group the tarsal claw of the female is not toothed, as it is in *anthracinum.* The absence of the ventral incisure, and the simple anal gills, suggest *Gigantodax* rather than *Simulium (Hearlea).*

There are thus grounds for considering that the species has no close affinity with *Austrosimulium,* from which it is so widely separated, geographically, but may finally be placed in a sub-genus of *Gigantodax,* or in a new genus intermediate between *Simulium (Hearlea)* and *Gigantodax.* Although the species is confined to Southern Chile, which might suggest a Southern origin, it is, in fact, mainly the ten-segmented antenna which suggests affinity with *Austrosimulium.* As reduction in the number of antennal segments is known in individual species of both *Simulium* and *Austrosimulium* this is not very strong evidence.

There is no evidence to suggest that *Gigantodax* is of southern (Antarctic) origin, other than the backward struts in the anal sclerite which it possesses in common with *Austrosimulium. Gigantodax* appears to be derived from Northern Hemisphere *Cnephia* stock.

It is hoped that the male will shortly be described by Dr Wygodzinsky, from specimens recently collected by him in Ushuaia, Tierra del Fuego, and that this will finally resolve the question of the generic position of the species.

Gigantodax sp.

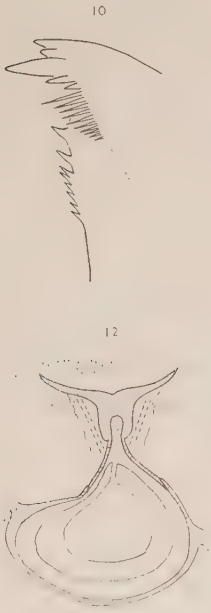
LARVA: Length 6 mm.

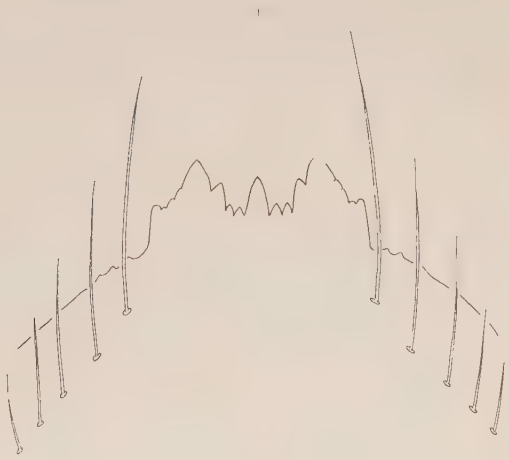
Head; light yellowish brown, with dark brown to black markings; the frontal pattern similar to that of *G. horcotiani* Wygodzinsky; a median longitudinal stripe, smaller submedian spots at mid-length on each side and a transverse posterior dark area. Ventral incisure absent; posterior tentorial pit, elongate, curved; a dark pigmented area extending from this pit nearly to the mid-ventral line. Postero-lateral margins of the frontal sclerite rounded. Post-frontal processes continuous with epicranium, tapering to end near mid-dorsal line. Antennae slightly shorter than basal piece of mouth brush; all segments pale in colour; 1 longer than 2, 3 plus 4 very slightly longer than 1 plus 2. Mandible (Fig. 10) normal, with 8 acute teeth on inner margin, the two distal teeth larger and more widely separated than the remainder. Mouth brushes normal, basal piece half as long as rays, with two short setae apically; rays slender, hairs fine, biseriate. Sub-mentum (Fig. 11) with 4 or 5 simple setae on each side, laterally with 2 or 3 teeth laterad of the sub-parallel sides of the apex; 5 teeth on each side of the median tooth, which is exceeded in length only by the 4th tooth on each side; 1 and 2 short, 3 nearly as long as median, 4th longest and broadest, 5th small somewhat rounded, a short obsolete tooth mesad of 5 and traces of two others between this and the apex of 4.

Thoracic proleg normal.

Abdomen normally tapered posteriorly, without *Cnephia*-form.

Anal gills simple trilobed. Anal scales divided apically; pre-anal scales pale; post-anal dense, black. Anal sclerite (Fig. 12) X-shaped; posterior





Gigantodax sp.

FIG. 10—Larva. Mandible.
FIG. 11—Larva. Sub-mentum.
FIG. 12—Larva. Anal sclerite.

arm with 3 or 4 short setae between it and crotchet ring; between the bases of the posterior arms is a paler oval enclosed area, with about 10 circular dark spots. Ring sclerite present, dorsal ends overlapping and articulating with posterior arms; pleural expansion less strongly pigmented, and with short dorsal and ventral arms. Backward struts present. Ventral tubercles present. Crotchet ring normal.

MATERIAL EXAMINED: Many larvae in two collections (FWN 3·2 & FWN 3·3) from a small steep stream 1–1½ ft wide, flowing into a lake. Four larvae (FWN 6·4) from a stream in a flat at 630 m elevation, above the forest. All collected by G. A. Knox, 20/1/1959.

No pupae were present, and none of the larvae had the gill-spots developed. All the larvae appear to belong to the one species, but this is not identifiable with any of the described species. They are similar in most respects to those of *G. antarcticum* (Bigot), the type of which was from Beagle Channel, *G. horcotiani* Wygodzinsky, and *G. chilense* Edwards.

This is the southernmost record for the genus, and the description may enable the species to be identified with one of those to be described from Ushuaia by Dr Wygodzinsky.

ACKNOWLEDGMENTS

The author is indebted to the Expedition Committee and to Professor G. A. Knox for the opportunity to study the material collected by Professor Knox during the Royal Society Expedition to Southern Chile in 1958–59; also to Dr P. Wygodzinsky, of the University of Buenos Aires, for his earlier gift of a pupa of *Austrosimulium anthracinum*.

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THE MEASUREMENT OF CARBON-14 AND TRITIUM ACTIVITIES IN GAS-FILLED GEIGER COUNTERS

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(Received for publication, 20 June 1960)

Summary

The construction of geiger counters and a vacuum system for filling them with ^{14}C-carbon dioxide or ^{3}H-hydrogen is described. The counters must be quenched electronically. The effect of the pressure of the filling gas and ambient temperature on the counters was investigated. Likely errors are discussed and are found to be consistent with the experimental reproducibility (about $\pm$ 1%).

Samples containing about 4×10^{-3} μ c/g carbon and 4×10^{-2} μ c/g hydrogen at the standard filling pressure (150 mm Hg) gave count rates equal to background (25 c/min).

Introduction

The use of radioactive tracers in chemical and biological experiments has become increasingly important, especially as the cost of radioactive isotopes has dropped considerably over the last few years. Of particular importance are the β-emitters ^{14}C and ^{3}H.

The activity of substances containing ^{14}C have in the past been assayed by preparing solid precipitates (e.g. barium carbonate) and placing them near to a thin end window geiger counter. This method is very inefficient for ^{14}C owing to the absorption of the β particles and the poor geometric conditions, and cannot be used at all for tritium whose particles have only $^{1}/_{10}$ the energy of ^{14}C β's. Increasing the specific activity of the sample is one solution, but it can be an expensive one.

The best method of assaying low energy β-emitters is to make them the filling gas inside an ionisation chamber, proportional counter, or geiger counter. They may also be dispersed or dissolved in a liquid scintillator solution and observed with a photomultiplier or sometimes two photomultipliers in coincidence. Liquid scintillation counters and their associated electronic equipment are very expensive and are not very efficient for counting tritium.

The estimation of ^{14}C or ^{3}H by gas counting has been used by many workers (Table 1). Both these isotopes have been used in this laboratory in chemical and biochemical studies. It seemed worthwhile to point out that the gas phase geiger counting of these two isotopes is a relatively simple method of high sensitivity provided certain tests, to be described later, are carried out on the counters to be used. Some of these tests have already been described by Eidinoff (1950). Simple filling mixtures have been chosen, as not all laboratories have supplies of argon, methane, ethylene, etc. which are often used to fill geiger counters. The advantages of this method over the method of counting solid precipitates are:

(1) The carbon dioxide or hydrogen sample may be measured directly into the counter which obviates the preparation of solid precipitates.
(2) No absorption or scattering corrections are needed.
(3) Up to 80% of the disintegrations occurring in the counter are recorded.
(4) A carbon-14 sample in the gas phase will give 50 to 100 times the count rate of the same sample as a solid precipitate counted with a thin end window G.M. tube. This factor is many times higher for the case of tritium (Eidinoff and Knoll, 1950).

TABLE 1—Types of CO_2 and H_2 Fillings Used for the Geiger Counting of ^{14}C and ^{3}H

Filling	Reference
Carbon di-oxide/carbon di-sulphide	Brown and Miller, 1947. Miller, 1947. Mann and Parkinson, 1948. Eidinoff, 1950. Henson, 1953.
Carbon di-oxide/ethanol/argon	Engelkeimer *et al.* 1949. Broda and Sverak, 1954.
Carbon di-oxide/ethanol	Apelgot, 1957.
Carbon di-oxide alone	Apelgot, 1957.
Hydrogen/ethanol/argon	Eidinoff, 1947.
Hydrogen/ethylene/argon	Wolfgang and Libby, 1952.
Hydrogen/methane	Verly, 1952.

EXPERIMENTAL

Construction of Counters

The cathode was made either of thin copper sprung against the inside of the glass tube, or of chemically deposited silver covered with aquadag. The second type of cathode has the merit of being easily constructed but the graphite has a tendency to peel off after several months' use. The anode wire was 0·15 mm tungsten wire. The constructional steps are shown in Fig. 1. Tungsten spotwelded to a strip of nichrome was sealed in so that the nichrome touched the inside wall in order that there should be a connection from the silver layer to the outside of the counter. The tube was then silvered, the glass sleeve being protected by a rubber glove, R. After drying and polishing, the silver was covered with aquadag from a thin suspension of the substance in water. The second glass sleeve was sealed in (1b) and

the two ends opened ready for the insertion of the tungsten wire. Tungsten wire and the phosphor bronze spring (made from 0·01 in. wire) (Fig. 1c) were threaded through the counter sealed at A then at B, making sure the wire was kept taut during the sealing process. The completed counter is shown in Fig. 1d. The same procedure was followed when making counters with copper cathodes except that the thick tungsten and nichrome was sealed to the copper sheet at N.

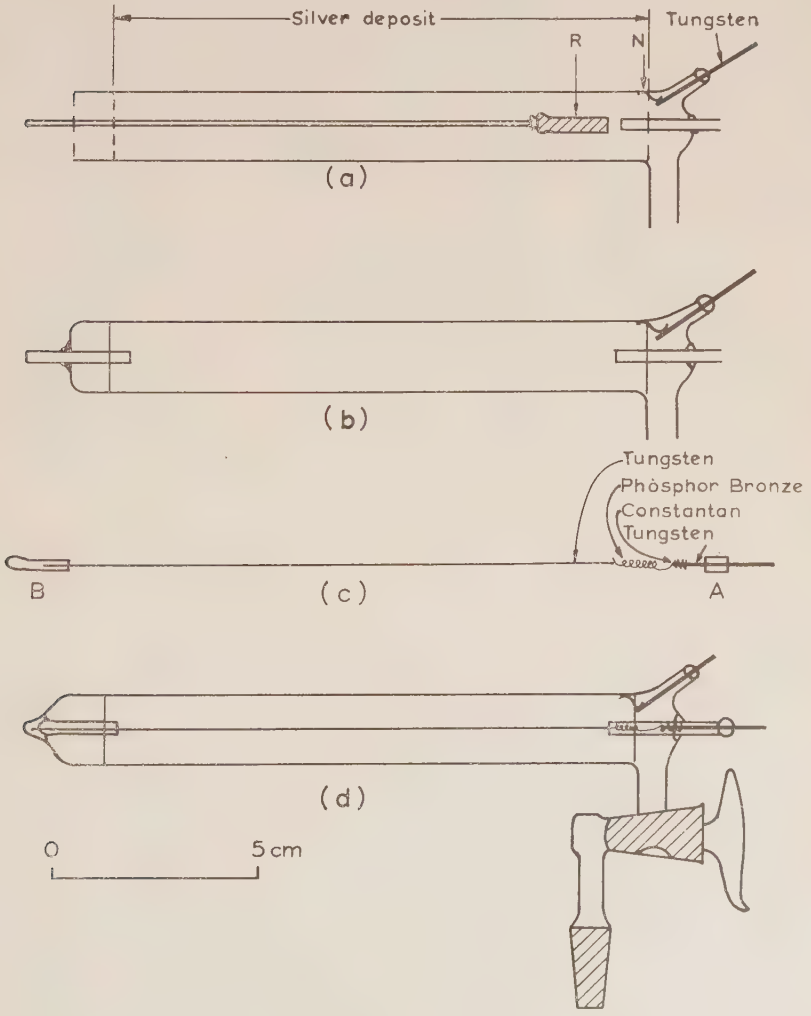

FIG. 1—Construction of counters.

Preparation of Samples

The vacuum system used for filling the counters is shown in Figs. 2 and 3. The connection C was connected to a cold trap, mercury diffusion pump and a rotary backing pump.

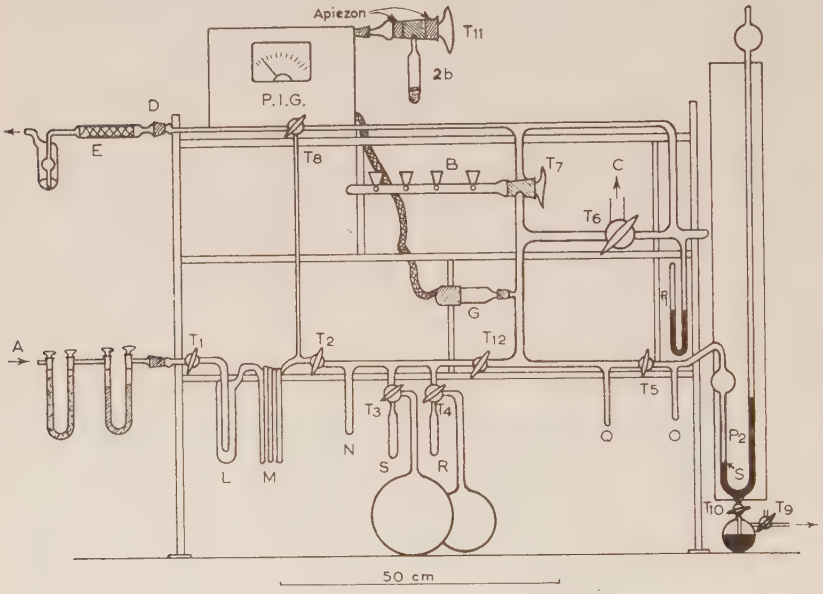

FIG. 2—Vacuum system.

Carbon Dioxide Samples

Carbon dioxide was dried with U-tubes containing P_2O_5 and condensed in M (Fig. 2) cooled with liquid oxygen. After pumping on the traps the CO_2 was transferred to the finger N cooled with liquid oxygen. A dry ice/acetone mixture was then placed around N, the CO_2 distilled into O cooled with liquid oxygen and the pressure of CO_2 in the manometer determined with the mercury at the fixed mark S. The volume of the manometer was previously determined by freezing CO_2 of known pressure into the manometer from a finger of known volume.

The geiger counters to be filled were attached to the manifold B, pumped down and filled with carbon disulphide vapour (20 ± 2 mm Hg) from a finger containing the liquid (2b). A suitable amount of carbon dioxide was frozen from the manometer into the counter by placing a cold trap around the lowest part of the counter and finally the counter was pumped until the pressure dropped to about $0{\cdot}2\mu$. In the counters used here, the carbon dioxide filling pressure was kept between 150 and 200 mm Hg.

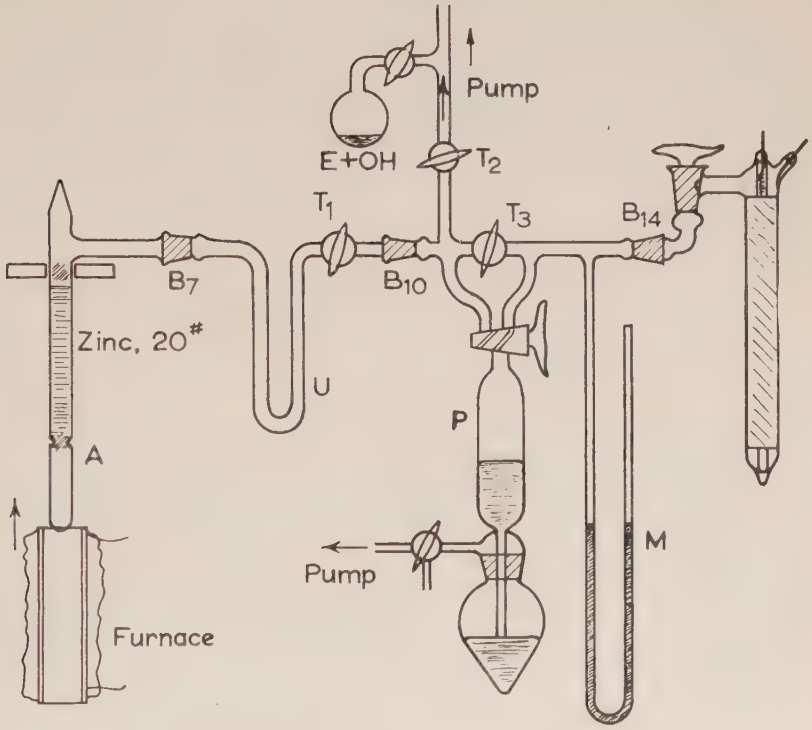

FIG. 3—Apparatus for preparation of Hydrogen.

Hydrogen Samples

Hydrogen gas for filling the geiger counters was prepared with the apparatus shown in Fig. 3. The zinc reduction tube filled with about 12 g of zinc, was first attached to the B 10 cone through an adaptor, evacuated, heated to 390°C with the small furnace, cooled, and dry air let in via the B 14 joint. Water containing the tritium to be estimated was frozen from the combustion furnace into the tube U and the tap T_1 closed. The complete apparatus in Fig. 3 was then assembled. The counter tube was filled with 15 mm of ethanol vapour (as indicated by the manometer M) and the remaining vapour pumped out. The tube U was immersed in a cold trap, T_1 opened, and the apparatus pumped to 0·5μ. The water in U was transferred to the lower part of A by placing a cold trap around A. The zinc was now heated to 400°C while the apparatus was pumped, T_2 and T_3 were turned off and the cold trap removed from A. Water at 20°C was placed around A and the hydrogen produced pumped into the counter with the Toepler pump. The hydrogen filling pressure was kept in the region of 200 to 250 mm Hg. One charge of zinc could reduce about eight 100 mg water samples.

Counting Procedure

The high voltage necessary for the operation of the counters was obtained from a regulated R.F. supply with a maximum voltage of 2·5 kV. The counters were not self-quenching and it was necessary to ensure that discharge was quenched immediately after the ionising event. A standard quench circuit was used which applied a 200 volt negative pulse of about 1·2 millisec. duration to the anode wire. The length of this pulse determined the paralysis time τ of the counter. The counts lost during this interval were computed from

$$N = R/(1\text{-}R\tau)$$

where N = true counting rate (c/min)

R = observed rate

τ = paralysis time (min)

A nomogram (Fig. 4) has been constructed from this equation to allow this correction to be easily made; the number of counts per min Δ, to be added to the observed rate R for any paralysis time τ between 0·2 and 3·0 millisec may be directly read off.*

The operating point of the counters was set at 80 ± 10 volts above the threshold, the threshold being defined as that voltage where the count rate was $^2/_3$ the count rate on the plateau. An external γ source was often helpful in locating the threshold.

RESULTS

The use of aquadag (colloidal graphite) on the silver cathode as recommended by Brown and Miller (1947) gave spurious counts, as indicated by abnormally high backgrounds. Apelgot (1957) has also noticed spurious pulses and photosensitivity from graphite-coated cathodes. After several months' use such counters were generally quite unusable. Counters with copper cathodes were also constructed and although the plateaus were steep (up to 5% per 100 volts) the background counting rate was low and stable. Plateau slopes of about 5% per 100 volts have been obtained by other workers using the CO_2–CS_2 mixture.

The operating voltage of the CO_2–CS_2 counters was about 2·4 kV for a CO_2 pressure of 150 mm Hg. A hydrogen/ethanol filling with H_2 of 200 mm Hg pressure was operated at 1,500 volts. The plateau length for all fillings extended over about 200 volts.

A number of tests were conducted on the counters in order to fully assess their capabilities for routine gas counting. All counting errors are given as standard deviations, that is, the probable error at the 67% confidence level.

*Copies of this nomogram are available on request.

Effect of the Filling Pressure on the Background

The counters were filled with 20 mm of carbon di-sulphide vapour, successive amounts of carbon dioxide added and the shielded (4 cm of lead) background determined. The results are given in Table 2. An abnormally high background was sometimes obtained. Such samples were improved by distilling the sample from the finger cooled with a dry ice/acetone mixture.

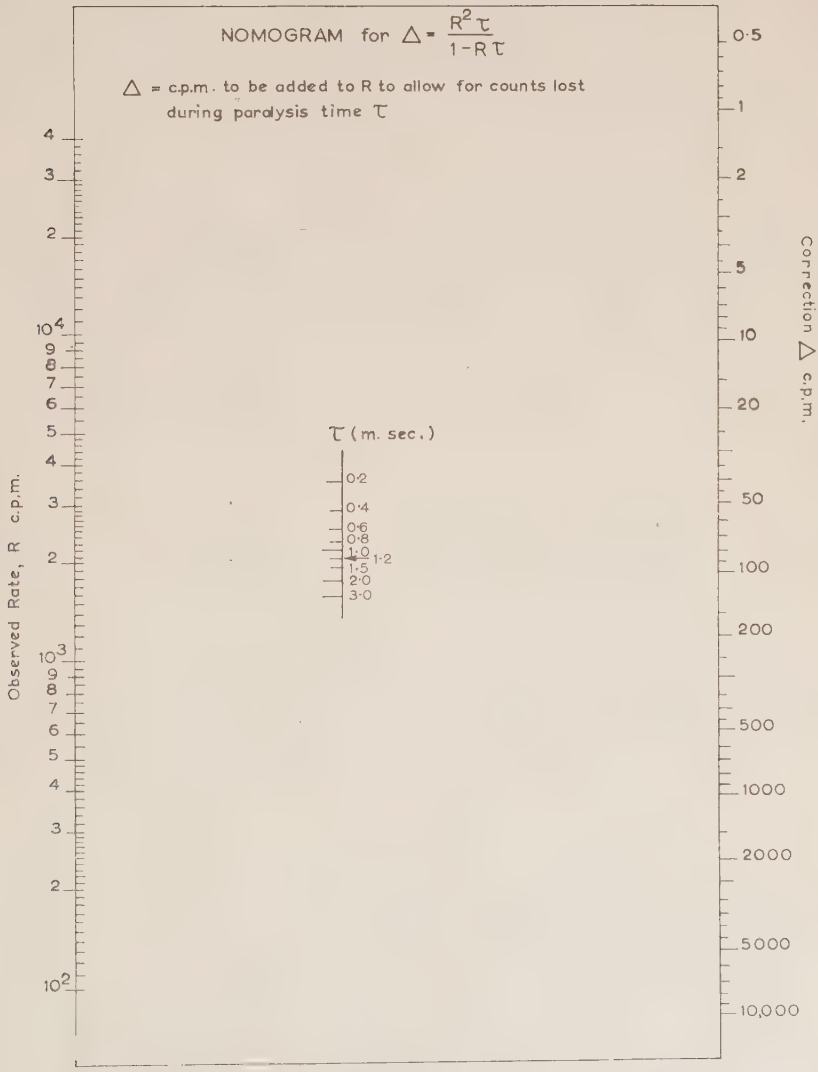

FIG. 1—Nomogram correcting for counts lost during paralysis time τ.

TABLE 2—Effect of Filling Pressure on the Background Counting Rate

Counter	Pressure (23°c) (mm Hg)				Background c/min
2	110	CO_2	20	CS_2	40 ± 2
2	570	,,	20	,,	45 ± 2
2	620	,,	20	,,	50 ± 3
5	80	,,	20	,,	45 ± 2
5	560	,,	20	,,	48 ± 3
6	95	,,	20	,,	22 ± 1
6	700	,,	20	,,	23 ± 1
8	60	H_2	16	EtOH	28 ± 1
8	300	,,	16	,,	29 ± 1

Effect of Pressure of Carbon Dioxide on the Counting Rate

Active carbon dioxide was added to a counter at different pressures and the count rate determined. A decrease in the observed counting rate was observed at high pressures. Assuming a paralysis time of $2{\cdot}5 \times 10^{-5}$ min, the corrected counting rates were found to vary linearly with pressure (Fig. 5).

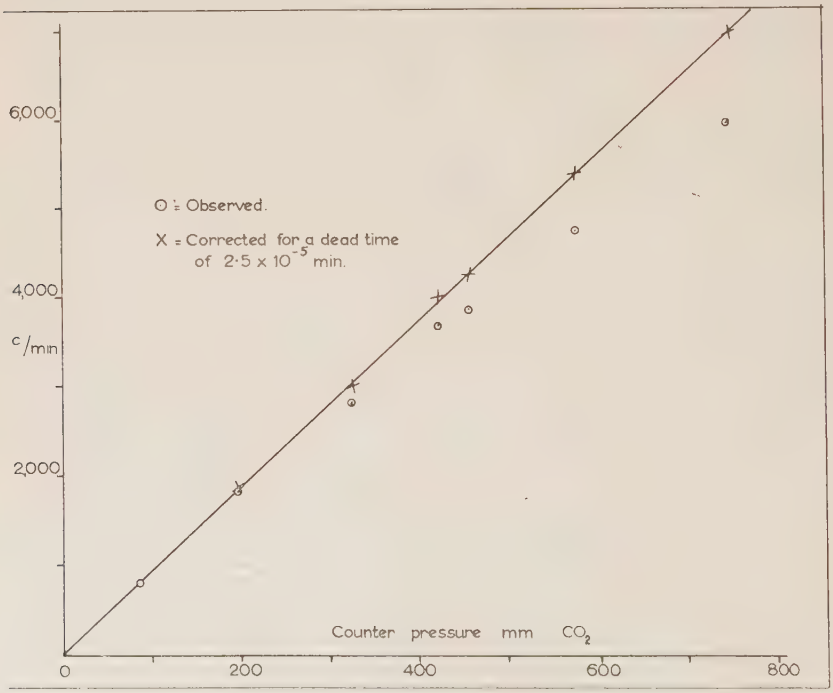

FIG. 5—Activity of a sample plotted against pressure of carbon dioxide.

Effect of Pressure on the Counting Rate at a Constant Partial Pressure of Active Carbon Dioxide

Changes in the counting rate on adding inert carbon dioxide to a counter containing active carbon dioxide could arise from changes in the sensitive volume of the counter with applied voltage. No change could in fact be detected (Table 3).

TABLE 3—Effect of Pressure on the Counting Rate at a Constant Partial Pressure of Active Carbon Dioxide

Counter	Total Pressure (23°C)	Rate c/min
2	100 mm Hg	1650 ± 10
2	300	1640 ± 10
5	300	3350 ± 20
5	680	3370 ± 20
6	150	1890 ± 10
6	590	1910 ± 10

Effect of Temperature on the Counting Rate of CO_2–CS_2 Counters

The counting rate of a sample was determined at different temperatures and a temperature coefficient of about + 0·05% per °C over the range 0°–40°C was found. Changes in the threshold voltage were not detectable over the temperature range investigated.

Memory Effects

No memory effects were observed after a sample giving 10,000 c/min was replaced with inert gas. The counter tube was surrounded with a beaker of hot water and pumped for 5 min between samples.

Counter Efficiencies

A carbon-14 standard (0·1 M Na_2CO_3 from the National Bureau of Standards, U.S.A.) was accurately diluted with inert Na_2CO_3, converted to CO_2 and frozen into the counters. The count rate was from 65%–75% of that calculated from the standard.

DISCUSSION

The gas counting of ^{14}C and ^{3}H is a simple, sensitive, and inexpensive way of estimating these isotopes. Apart from counting errors (sufficient counts to give an uncertainty of ± 0·5% at the 67% confidence level were usually recorded), the precision of the measurements depends on the accuracy of the pressure readings, possible isotope fractionation in the chemical processing and on the accuracy to which the operating point can be set. Errors due to fractionation could be quite high when preparing tritium and it is necessary to ensure that all the reduced hydrogen is pumped from the reaction tube. However, neglecting this error, if an error

of $\pm 0{\cdot}5\%$ is assumed for each of the three measurements listed above, a total error of about $\pm 0{\cdot}9\%$ may be expected. This agrees with the standard deviation for the results in Table 4.

TABLE 4—Reproducibility of Activity Measurements

Counter 5			Counter 6		
Date	Press. (mm)	μ c/g C	Date	Press. (mm)	μ c/g C
24/6/57	176	0.509	25/6/57	138	0.510
8/7	190	0.501	26/6	95.0	0.499
9/7	194	0.495	10/7	223	0.495
15/7	226	0.518	15/7	207	0.498
Mean = 0.506 $\pm$ 0.009 μ c/g C.			Mean = 0.500 $\pm$ 0.006 μ c/g C		

The methods described here could obviously be modified in some laboratories where liquid oxygen is not available. For example, carbon dioxide could be prepared from a dry carbonate by the addition of concentrated sulphuric acid in a vacuum and the carbon dioxide pumped with a Toepler pump into the counter.

When the counters were filled with CO_2 or H_2 to 150 mm Hg, samples containing 4×10^{-3} μ c/g carbon and 4×10^{-2} μ c/g hydrogen gave counting rates approximately equal to the background (25 c/min).

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